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SATURATED STEAM

THE MOTIVE POWER IN VOLCANOES & EARTHQUAKES.

R.A. PEACOCK, C.E. F.G.S.

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SATURATED STEAM

THE MOTIVE POWER

IN

VOLCANOES AND EARTHQUAKES;

GREAT IMPORTANCE OF ELECTRICITY.

SATURATED STEAM

THE MOTIVE POWER

IN

VOLCANOES AND EARTHQUAKES;

GREAT IMPORTANCE OF ELECTRICITY.

BY

R. A. PEACOCK, C.E., F.G.S.

SECOND EDITION, IMPROVED.

At the highest known terrestrial temperature, viz. hydrogen burning in oxygen=14,541° Fahr., the modification practically vanishes; leaving behind it the pure and simple law that the pressure of saturated steam increases as the 4·5 power of the temperature Fahr.

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1882.

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40 geographical miles atmospheric resistance	17,417	„ „
	17,534	„ „

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* As if all the water was used up by the active volcanoes.

SATURATED STEAM

THE MOTIVE POWER

IN

VOLCANOES AND EARTHQUAKES;

GREAT IMPORTANCE OF ELECTRICITY.

SECTION I.

Definition of the term saturated steam.

SATURATED STEAM.—This epithet (saturated) is used because it is the only correct and adequate description, and therefore the nature of things requires it; it is when there is always *abundance of boiling water* in the boiler, or cavity of the earth, as long as the active operation of producing steam continues. Thus more and more of this boiling water is continuously converted into more and more steam, and crowded again and again into the cavity by the increases of heat; and thus the steam is kept continuously saturated, until the pressure becomes so exceedingly great (we will suppose for the sake of argument) as to project from a volcanic mountain "immense columns of hot water and boiling mud, mixed with burning brimstone, ashes, and lapilli of the size of nuts . . . . like a waterspout, that large quantities fell beyond the river Tandui, which is 40

geographical miles distant." * This steam would necessarily be "saturated," on account of the presence of so great an abundance of hot water and boiling mud. The official Dutch statement is given in the sequel. (See Appendix B and foot-note at end of it.)

We ought always to remember that steam in its greatest development is one of the most gigantic forces in terrestrial nature.

SECTION II.

Definition of the term superheated steam.

Superheated Steam—Is a term appropriately used immediately after the last drop of water has been converted into steam; because then increases of heat, however great, can have no work to do except to make the steam already produced hotter, which increases its force *very little*, for the obvious reason that there is no more water left to be converted into additional steam, and consequently *the increase of power is at a standstill.* Therefore to superheat means to heat the steam higher than its normal temperature at which the last drop of water became steam.

The experiments and statements of an eminent deceased authority will now be quoted in support of these definitions of saturated and superheated steam.

* Fully 46 English miles. A geographical or nautical mile is 6075·6 English feet, and an English mile is 5280 English feet. *Crushing* of rocks would not propel lapilli 46 English miles; it would require a sufficiently powerful *explosive* force to do that.

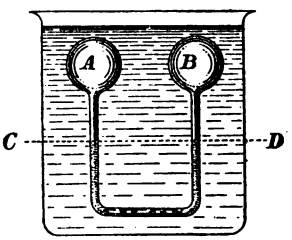
SECTION III.

Sir William Fairbairn's experiments—Diagram of his saturation gauge —His experiments on heated boiler plate—Extracts from his table of relations of temperature to volume of saturated steam—M. Regnault's steam experiments—Formula.

Useful Information for Engineers, by William Fairbairn, LL.D., F.R.S., &c., Second Series, 1860.

His difficulty was to find some sufficiently delicate test to determine the point of saturation. At page 310 he says: "This has been overcome by what may be termed the saturation gauge, and it is in this that the novelty and value of the present method consists.

SIR W. FAIRBAIRN'S FIG. 71.



"The simplest form of this gauge may be illustrated by the diagram, Fig. 71. Suppose two globes A and B, freed from air, and connected by the bent tube C D, which contains a portion of mercury. Suppose enough water introduced into A to be vaporised at a temperature of 290° Fahr., which corresponds with a pressure of 50 lb.;* and let any larger quantity be introduced into B; and let the water in A be separated from that in B by the mercury column C D. If now

* (*Sic.*) According to the present writer's mode of calculation, about 56 lb. and a fraction.

the globes be heated, the water in each will go on vaporising, and the pressure in each will go on increasing uniformly, until all the water in A is converted into steam. As soon as this point is reached the mercury columns will change their level, the column C rising nearly two inches for every degree Fahr. above the saturation point. The instantaneous rise of the column is the indication of the temperature of saturation. The cause of it will be perceived. As soon as the water in A is vaporised the pressure in that globe practically ceases to increase; but as water still remains in B, the pressure in that globe increases about one pound for every degree Fahr. The unequal pressure on the mercury column C D causes the rise observed. The increase of pressure resulting from vaporisation at 290° is about twelve times the corresponding increase for superheating or expansion, and for other temperatures the difference is about the same." *

* It may be asked, however, how does it happen then, if it be true that the increase of pressure in boilers is so small after all the water is converted into steam, that boilers so often burst for want of water? Sir William made numerous experiments on the strength of boiler plate at various temperatures, and found that iron is much weakened when it arrives at "scarcely red" and "dull red" heat, which of course it soon would do if there was no water in the boiler.

ON THE TENSILE STRENGTH OF WROUGHT-IRON AT VARIOUS TEMPERATURES.

	Mean breaking weight per square inch in lbs.
212° Fahr. mean of three experiments	45,005
"Scarcely red" / "Dull red"	34,272

NOTE.—Iron at 212° Fahr. had the greatest strength of any. Thus iron at "dull red" heat has lost about $\frac{2}{3}$ of its strength. And at higher temperature it will become still softer and weaker.

Sir William then gives a drawing, Fig. 72, of a suitable apparatus constructed on this principle which he "employed with success." By the use of this apparatus he made the experiments of which he gives the results in a table at p. 313. The following are extracts from his table.—*Ibid.*, p. 313.

TABLE OF RESULTS, SHOWING THE RELATION OF DENSITY AND PRESSURE OF SATURATED STEAM.

Pressure in lbs. per square inch.	Temperature Fahr.	Specific volume from experiments.
2·6	136°·77	8266
26·5	242·90	941
60·6	292·53	432

"They appear, however, to show conclusively that near the saturation point steam expands very irregularly."

Some few years ago, when the present writer was examining and considering M. Regnault's steam experiments* (of which Sir William very truly said, "they have all but mathematical accuracy"), he found that below the temperature Fahr. 285·098°, which gives a pressure of 52·529 lb. per square inch, all his efforts to discover a mathematical law for *smaller* temperatures and pressures were quite in vain and fruitless (except to establish the fact of this irregularity); in fact he satisfied himself that they *are* irregular and follow no mathematical law.

* Mém. de l'Institut, tome xxi., 1847.

At higher temperatures than 285·098° Fahr., however (at all events up to 426·996° Fahr.), the natural law of increasing pressure is this very rapid ratio of increase of pressure, namely:—

The pressure in lbs. per square inch increases as the $4\frac{1}{2}$ *power of the temperature Fahr.* This is called Rule A at the head of all the columns worked by it in Tables I., II., and III. following.

See Table I. on page 110 following. Of this table it is sufficient to say here that the difference between experiment and calculation never amounts to as much as a *unit per cent.* (see column **5** of the table). Please observe—

The pressure increases (within the limits of Table I. at least) in the enormously rapid ratio as the $4\frac{1}{2}$ *power* of the temperature. This is very suggestive.

Columns **6** and **7** are the practical results, which the reader would do well to examine carefully.

The correctness of columns **6** and **7** may be considered quite certain, and therefore we may take it as an ascertained fact that we know, within their limits, the relations which temperatures bear to pressures in saturated steam.

SECTION IV.

Tremendous volcanic explosions in Java—Their effects—White hot water—Java explosion not unique—Cotopaxi—Conseguina—Jeddo—Lisbon earthquake.

Sir William's table of moderate pressures and temperatures, and the diffuseness of his two first "specific volumes" in the preceding extracts from it, are of course only differences in degree (*not* differences in principle) from their equivalents in Table I., and *à fortiori* from the violent volcanic actions in Java, detailed in Appendix B. It is there stated (and authenticated by a foot-note at the end) that "every valley within the range of the eruption became filled with a burning torrent, and the rivers, swollen with hot water and mud, overflowed their banks. . . . A space of twenty-four miles between the mountain and the river Tandui was covered to such a depth with bluish mud that people were buried in their houses. . . . It was remarked that the boiling mud and cinders were projected with such violence from the mountain, that while many remote villages were utterly destroyed and buried, others much nearer the volcano were scarcely injured. . . . Four days after a second eruption occurred, more violent than the first, in which hot water and mud were again vomited, and great blocks of basalt were thrown to a distance of seven miles from the volcano. There was at the same time a violent earthquake."

What were the burning torrents about? What the boiling mud projected to many miles distance? What the second and more violent eruption, when great blocks of basalt were thrown to seven miles distance? Will any man venture to deny that saturated steam was the active agent on these occasions? Man should expand his ideas, and grasp mentally these tremendous operations of Nature in all their magnitude. What she does on the grand, he can only do on the little.

It is well known that water, when strongly enclosed, say by rocks in a volcano—may be heated far *above* boiling point, which doubtless was the case in Java. And when the pressure from within became strong enough it burst the rocks and projected the lapilli. In fact, Sir Charles Lyell, speaking of a column of red-hot lava, says: "mixed with *red-hot* or *white-hot water* (for water may exist in that state, as Professor Bunsen reminds us, under pressure)."—*Principles of Geology*, vol. ii., 1868, p. 221.

This white water would flash into the most violent steam the moment it became white enough, that is, strong enough to burst the rocks which imprisoned it, and would commence its long flight of forty miles. The expression "burning torrent," in Appendix B, is significant of heat widely greater than the ordinary boiling point. A calculation will be given presently, as soon as certain necessary preliminary statements have been made, of the amount of force required,

which comes out 17,534 tons per square inch for the Java explosion.

The Java explosion has not been *unique* in the magnitude of its force. By no means. Sir Charles Lyell tells us:—"The volcano of Cotopaxi has been known to throw out, to the distance of eight or nine miles, a mass of rock about one hundred cubic yards in volume."* Which, if it was granite, would weigh just 200 tons.

Again: The volcanic mountain Conseguina, in Central America, exploded in January 1835; there was a tremendous subterranean report as of a thousand cannon, heard at several hundreds of miles distance. *Clouds of steam continued to rise from the volcano* for months after.† Humboldt says it was heard at nearly 560 geographical miles distance.‡

Again: The earthquake by which Jeddo was destroyed in 1783, destroyed twenty-seven other towns and villages, totally. *Boiling rivers overflowed their banks*, and at least 180,000 people are said to have perished.§

Once more: Humboldt says, "It has been computed that on the 1st November, 1755, by the Lisbon earthquake, a portion of the earth's surface four times greater than that of Europe was simultaneously

* 'Principles of Geology,' vol. ii., 1863, p. 223.

† 'Travels in Central America,' by Dr. Carl Scherzer, vol. ii. p. 224, &c.

‡ Bohn's 'Cosmos,' vol. v. p. 275.

§ 'Quarterly Review,' Oct. 1863, p. 461.

shaken."* It follows that nearly one-thirteenth of the whole surface of the globe received a shock on that occasion. The shocks extended through great part of the length and breadth of the North Atlantic. From Africa and Lisbon to the West Indies, and from Madeira to Loch Lomond. And it may well have been the fact, that water got down from the bed of the ocean to the heated matter beneath. This great earthquake will be referred to again.

When there were such tremendous explosions of mountain Galangung, in Java, of course they made the *earth quake* all round. And accordingly the narrative (Appendix B) tells us that on the 12th "there was at the same time a violent earthquake." The like has happened and will happen again, to produce earthquakes, in other active volcanoes.

SECTION V.

Greatest terrestrial heat—Professor Tyndall—His greatest temperatures.

Greatest Heat attainable by Man.

As we are contending that saturated steam propelled lapilli (little stones) and other *ejectamenta* to the immense distance of forty miles through the air, it is incumbent on us to prove that steam can be heated sufficiently to accomplish so great an exploit.

* 'Cosmos,' vol. i. p. 203.

Professor Tyndall will instruct us on this point.* He gives his temperatures in Centigrade degrees, which the present writer has converted into Fahrenheit by the usual process, and enclosed them in brackets to show that he and not the Professor is responsible for them. The latter says:—

"The most intense terrestrial combustion that we can command is that of oxygen and hydrogen, and the temperature of the pure oxyhydrogen flame is 8061° C. [14,541° F.]. The temperature of a hydrogen flame burning in air, is 3259° C. [5898° F.]; while that of the lime light, which shines with such sun-like brilliancy, is estimated at 2000° C. [3632° F.]."

These are enormously high temperatures; more than sufficient, we submit, gradually to accumulate between July and October (see Appendix B) sufficient force of steam to propel the lapilli, &c., forty miles.

We will now prove by a quotation from 'Chemistry' that, since both air and water were present in the volcano of Java, oxygen and hydrogen were necessarily present also. For those gases are constituents of air and water. Moreover, we cannot doubt that electricity was present also to decompose them into their constituent gases. For it is notorious that electricity has often been seen active in volcanoes.

* 'Heat considered as a Mode of Motion,' 1865, by John Tyndall, F.R.S., &c., p. 485.

SECTION VI.

Ure's Dictionary—Constituents of air—A. Crum Brown—Constituents of water—Abich detects hydrogen in Vesuvius—Bunsen, St. Claire Deville, and Fouqué, prove escape of hydrogen during eruptions—Professor Judd's 'Volcanoes.'

From Ure's *Dictionary of Arts, Manufactures, and Mines*, 1860.

Air consists of the gases nitrogen and oxygen. About 75 measures of nitrogen or azote, and 21 of oxygen, with $\frac{1}{100}$ of carbonic acid, constitute the air we breathe.*—*Chemistry*, by Alex. Crum Brown, M.D., D.S., 1875, from whom the following paragraph is quoted.

"The discovery of the composition of water was made by Cavendish in 1781. He showed that, when hydrogen gas is burnt in the air, water is formed, and that if instead of common air (which contains about 21 per cent. of oxygen) pure oxygen is used, the hydrogen and oxygen disappear, and water is produced, and *that the weight of the water formed is the same as that of the hydrogen and oxygen which have disappeared.*

"Oxygen weighs sixteen times as much as hydrogen. By *weight*, 8 oz. of oxygen to 1 oz. of hydrogen = 9 oz.

	Volume.
* Oxygen	20·96 per cent.
Nitrogen	79· „
Carbonic acid	0·04 „
	100·00

—*Encyclopædia Britannica*, Art. "Atmosphere."

water. The composition of water was discovered by *synthesis*, i.e. by forming it from its constituents. This may be done by passing through water a current of electricity . . . the hydrogen produced fills just twice the space filled by the oxygen." P. 29.

"M. Abich remarked . . . . he had clearly detected the flame of hydrogen in the eruption of Vesuvius in 1834."*—*Principles of Geology*, vol. ii., 1868, p. 224.

It may be observed "that the flame of hydrogen would rarely be visible during an eruption; as that gas, when inflamed in a pure state, burns with a very faint blue flame, which even in the night could hardly be perceptible by the side of red-hot and incandescent cinders. Its immediate conversion into water, when inflamed in the atmosphere, might also account for its not appearing in a separate form.

"The observations of Bunsen in Iceland in 1844, of St. Claire Deville on Vesuvius in 1855 and 1861, and of Fouqué on Santorin in 1866, have proved that there is an abundant escape of hydrogen, both in a free state and in combination with other substances, during eruptions."—*Ibid.*, p. 225.

The present writer has before him 'Volcanoes,' by Professor J. W. Judd, F.R.S., an important and valuable work, containing 95 admirable illustrations. Mr. Judd has placed on record, to the great advantage of Science, many facts observed by himself and others at Stromboli and Vesuvius during their states of activity;

* 'Phenom. Geol.,' &c., p. 3.

and the following two pages are an abstract of pp. 19 to 31 of 'Volcanoes,' which contains matter of importance to the present publication.

Professor Judd on Stromboli and Vesuvius.

Bottom of crater of Stromboli reminds one of the appearances of liquids boiling—vast bubbles are formed on its surface—as temperature rises steam is generated within—when pressure is relieved by bursting of bubbles, the whole of the steam tends to escape suddenly—so with entangled water of Stromboli—violent escape of pent-up steam.—Water subjected to great pressure may be very highly heated, and yet remain liquid; but from any opening steam escapes with prodigious violence—when plenty of water is present, steam is said to be *saturated* [not superheated]—sometimes roaring of steam jets is heard for many miles—incandescent liquid rock flows down from craters and fissures.

Vesuvius sometimes erupts on the very grandest scale—eruption of April 1872 has been much studied—Judd's excellent photo., No. 5, exhibits Vesuvius 4000 feet high, with vapours, and rocks thrown 20,000 feet high, i. e. 4 miles.

Professor Palmieri said "*Vesuvius sweated fire*"—enormous volumes of steam rushed out with prodigious roaring sound, so terrific that people of Naples, 5 miles off, fled and slept in the streets—at a distance the g sound seemed to be continuous, but those on

the mountain perceived detonations rapidly following one another*—each explosion was accompanied by a great globe of white vapour, rising into the air and swelling the bulk of the vast cloud overhanging the mountain—inspection of photos. (fig. 5) proves that the great vapour cloud over Vesuvius was made up of globular masses, ejected at successive explosions—the largest lava flood overwhelmed and destroyed two villages—lava floods gave off during their flow enormous volumes of steam, which are seen in photo.—the steam blistered the rocks.—Before and during the outbreak of Vesuvius in April 1872, the mountain and whole country round were visited with earthquake shocks—another striking phenomenon was the vivid display of lightning accompanied by thunder—uprushing steam and rock fragments formed a vertical column, around which the most vivid lightning constantly played—Judd quotes Sir W. Armstrong, of whom more in Sec. VII.—restoration of electrical equilibrium was attended with frequent lightning flashes and thunder claps drowned in the still louder roar of uprushing steam—great rain of condensed steam follows—the degree of violence of explosions depends on abundance and tension of steam.

* Each of these rapid detonations would decompose a portion of water into hydrogen and oxygen, which would burn together, producing a heat of 14,541° Fahr., which would melt old rocks into new lava, and would accumulate large quantities of saturated steam of sufficient force to propel Mr. Judd's rocks 20,000 feet high.—R. A. P.

SECTION VII.

Sir W. Armstrong proves electricity of boiler steam—Abstracts of his letters—Professor Faraday's remarks—Pattinson on electricity of high-pressure steam—Armstrong on electricity of effluent steam—Pattinson's experiments on steam of locomotive engines—Armstrong on electricity of effluent steam—Effects of mixing various substances with the water—Boiler steam necessarily saturated—Van der Boon Mesch on Galangung, in October 1822, proves emission of lightning—Sir W. Hamilton proves emission of lightning from Vesuvius, August 1779—Dr. Carl Scherzer proves electric discharges from Conseguina, January 1835—These decompose water into hydrogen and oxygen, which burning together may in extreme cases give out a heat of 14,541° Fahr., which will give saturated steam of proportionate power—Simultaneous electric explosions at Vesuvius and Galangung, 6315 geographical miles apart, are not surprising—Terrestrial forces of to-day quite sufficient to account for greatest volcanoes and earthquakes—No need to look to primary heat or astronomical causes—Humboldt on Conseguina in January 1835—Darwin on Conseguina communicating with Aconcagua and Corcovado within 6 hours, 3380 geographical miles—Mr. Darwin's difficulty appears explainable.

The present writer's chief object in quoting from these letters is to prove:—*First*, that steam *very often* produces electricity. *Second*, that it need not necessarily be steam of very high pressure; only about from 5 to 52 lb. per square inch, and therefore that volcanoes may, and doubtless often if not invariably do, produce electricity (with all its consequences) in their state of activity. *Third*, that as far as the present series of experiments extended, the quantity of electricity increases and diminishes with the pressure. *Fourth*, that

this electricity being probably always present in volcanoes, there is a ready means at hand for decomposing water and atmospheric air into their respective constituent gases, among which oxygen and hydrogen hold such large and important places. And thus we can account for the extremely high temperatures mentioned on p. 11, which prove in turn the existence of saturated steam of extremely great power, such as would account for the most violent action of volcanoes and earthquakes.

Electricity of a Jet of Steam issuing from a Boiler. By W. G. Armstrong, Esq., in Letters to Professor Faraday, Nov. 1840.*

Abstracts of the Letters.

The boilers stood at Seghill, 6 miles from Newcastle-on-Tyne. They are ordinary boilers, set in the usual manner. The electric steam issues horizontally from under the safety valve, through a cement composed of chalk, oil, and tow. The boiler had been cleaned out the day before Mr. A. saw it, and a thin incrustation of calcareous matter, reaching as high as the water level, had been removed; and the consequence was, that the indications of electricity, though still existing, were very much diminished. The valve was loaded at the rate of 35 lb. per square inch, but the pressure of the steam fluctuated considerably, which gave Mr. A. an opportunity of observing that the quantity of electricity

* 'Philosophical Magazine,' vol. xvii., 1840, p. 370 et seq.

derived from the jet increased and diminished with the pressure. The electricity of the steam was *positive*. There were several small jets of steam issuing from the boiler, all of which yielded electricity. The engine has another boiler adjacent. When its safety valve was raised the column of steam which escaped proved as highly charged with electricity as the horizontal jet which issued from the other boiler. The water used in the boilers was obtained from a neighbouring colliery. A third boiler supplied with the same water also yielded electricity from its steam. A fourth boiler supplied with *rain* water (pressure 40 lb. per square inch)—no trace of electricity in the steam from this boiler. He sent Professor Faraday a specimen of the incrustation deposited by the water from the mine in the boiler in which it is used.

Then following are Professor Faraday's remarks, with his initials, M. F :—

"The incrustation is grey and hard, it contains traces of a soluble muriate and sulphate, but consists almost entirely of sulphate of lime, with a little oxide of iron and insoluble clayey matter, carried in probably by the water. There is hardly a trace of carbonate of lime in it.—M. F."

"The evolution of electricity by vaporisation, described by Mr. Armstrong, is most likely the same as that already known to philosophers on a much smaller scale, and about which there are as yet doubts whether it is to be referred to mere evaporation, as Harris says,

or to chemical action, according to others. This point it neither settles nor illustrates; but it gives us the evolution of electricity during the conversion of water into vapour, upon an enormous scale, and therefore brings us much nearer to the electric phenomena of volcanoes, waterspouts, and thunderstorms, than before. —M. F."

Then follows, page 375, *Experiments on the Electricity of High Pressure Steam*, by H. L. Pattinson, Esq., F.G.S.

Abstracts.

He examined the boilers just described; they are cylindrical with circular ends, each 21 feet long, and 5 feet diameter. The steam is worked at a pressure of 35 lb. per inch. He made experiments of which this is the fourth. On holding a large shovel in the current of steam with one hand, and touching the boiler with a pen-knife held in the other, a spark was obtained three-eighths of an inch long. From this it was evident that the electricity proceeded from the steam. Exp. 10, a small jar was now charged so strongly as to give a rather disagreeable shock. It would appear that the steam of both boilers was in the same electrical condition.

On the Electricity of Effluent Steam, by W. G. Armstrong, Esq., page 452. He says:—

"I then proceeded to try a number of boilers in this town [Newcastle-on-Tyne] and neighbourhood, in which the steam was propagated under different pressures, and

from water of various descriptions; and by insulating myself, and holding a conducting rod in the steam discharged from the safety valves, I succeeded in every instance in obtaining electrical sparks, which varied in the different cases from about a quarter to half an inch in length.

"In company with Mr. Robert Nicholson, the engineer of the Newcastle and North Shields Railway, I next tried the boilers of the locomotive engines used on that railway; and, finding electricity in great abundance in the ejected steam from those boilers," he determined to institute experiments on one of them, and did so "with an iron rod terminated at the end next the hand with a round knob (standing on an insulating stool); and from this knob sparks of the *measured length of four inches* were actually drawn, almost as rapidly as they could be counted, while a stream of electricity was at the same time passing off from the rod, at the part which most nearly approached the chimney of the engine. Very perceptible sparks were also obtained, when the points were held in a clear atmosphere, at the distance of at least 8 feet from the nearest part of the jet.

"In all the preceding experiments the effect appeared to be proportionate to the quantity of steam discharged from the valve, when other things remained the same; and the electricity became quite imperceptible when the escape was very inconsiderable."

"By abruptly raising the valve when the engine-shed was dark, the edges of the lever and margin of the brass cup which surrounded the valve were rendered distinctly luminous with rays of positive electricity, which were strongest the instant the valve was lifted, and then quickly subsided, becoming very faint after lapse of a second."

He asks:—Is the steam electrical in the boiler? Or in passing through the orifice? Or in the air?—No electricity in the boiler; "the electrical development does not appear to depend upon the degree of violence with which the steam comes in contact with the atmosphere."

"The condensation which took place in the jet, set free the electricity which the steam had absorbed in the process of evaporation."

Mr. Pattinson's experiments, page 457 et seq.:—

The *Wellington* engine, on arrival with passengers—steam blowing off from safety valve at a pressure of 52 lb. per inch. With a copper conductor, knob at one end and points at the other, the points being held in the steam, and standing on an insulating stool, sparks three or four inches long were given off from his person at the boiler. The electricity was positive. At 40 lb. per inch the sparks became much less. At 30 lb. the largest spark did not reach two inches. At 20 lb. it became hardly an inch. At 10 lb. a quarter to half an inch. At 5 lb. the sparks were hardly perceptible.

The *Lightning* engine, steam blowing off at 50 lb. per inch, only yielded a spark a quarter of an inch long. Having blown out the water till it barely covered the tubes inside, the spark increased to nearly two inches long. Steam of *Lightning* much less electrical than that of *Wellington* under same pressure. He made other experiments and says:—"These experiments enable us I conceive to give a clear explanation of the electrical phenomena presented by steam. There is no doubt whatever, as Dr. Faraday conjectures in his note to Mr. Armstrong's paper in your last number, that this evolution of electricity by vaporisation is the same as that already known to philosophers on a much smaller scale. The electricity appears to originate at the instant of vaporisation, and the steam as it collects within the boiler is electrified with positive electricity, the water and metallic boiler being at the same time negative."

On the Electricity of Effluent Steam, by W. G. Armstrong, Esq., 'Philosophical Magazine,' 1841, page 50, vol. xviii.

The negative electricity increased *a little* with the pressure; but the positive electricity drawn by the pointed conductor from the issuing steam increased *enormously* as the density of the steam was augmented.

Vol. xix. p. 25.—"By dissolving a little potash in the water from which the steam was generated . . . . the quantity of electricity was amazingly increased.

Soda had much the same effect as potash; steam positive, development not quite so strong. A minute quantity of nitric acid causing negative electricity. Muriatic acid had no perceptible influence, nor had sulphuric acid, even when iron filings were contained in the boiler. Lime tended to produce positive electricity, but not powerfully. Common salt appeared to have no effect. Nitrate of copper rendered the steam negative, &c."

Mr. (now Sir William) Armstrong signs his important and valuable statement at the end.

Each of these boilers would have a considerable quantity of hot water in it; and therefore all the steam would necessarily be *saturated* steam.

Thus we have seen that on all occasions except one,* the generation of steam gave out electricity; and that one exception, where rain-water was used to produce the steam. This water was probably almost, if not altogether, *pure* water, without any admixture of solid substances, either mechanically suspended in it, or chemically combined with it. We shall have an account presently of Vesuvius giving out plenty of electricity, both positive and negative.

The present writer has not perceived, until within the current month (January 1882), the important bearing which electric action has on volcanic action. There are *three* striking examples of this, which will now be quoted. The *first* relates to Mount Galangung in Java,

* And, *exceptio probat regulam.*

in October 1822, which has so often been referred to already:—

Van der Boon Mesch, *De incendiis montium Javæ, &c.*, Lugd. Bat. 1826, says, pp. 44–45:—

"Interdum nubes quæ cœlum et montem abscondunt, elidunt terribilia fulgura; his icti alii concidunt, alii vulnerantur . . . . undique cadunt imbres limi, cineris et ^^pidum horumque magnitudine nucis."

The *second* example we quote from Sir William Hamilton, Phil. Trans. R.S., 1780, vol. xiv. p. 616, &c., relating to Vesuvius:—

On August 8th, 1779, there was a loud report; and instantly a volume of liquid transparent fire rose as high as the mountain itself, puffs of very black smoke accompanied, and at the same moment could be seen bright electrical fire playing briskly in zigzag lines.*

Thirdly, in *Travels in the Free States of Central America*, by Dr. Carl Scherzer, vol. ii. pp. 224–7:—

During the eruption of the volcanic mountain Conseguina, January 20–23rd, 1835, there was a noise as of many cannon from various parts of the Gulf of Fonseca. Scherzer says, vol. ii. p. 227, "The regularity of the intervals between the detonations, and their continual

* Sir W. Hamilton mentions this circumstance to prove that the electrical matter so manifest during this eruption actually proceeded from the bowels of the volcano; and was not attracted from a great height in the air, and conducted into its crater by the vast volumes of smoke. See foot-note, Phil. Trans., R.S., vol. xiv. p. 616.

repetition, soon made it evident that the thunder did not proceed from the electrical discharges of clouds in a high region of the atmosphere, but from below in the bowels of the earth."

It is evident that these powerful electric shocks must each of them necessarily decompose water and air into their respective constituent gases, and that there will be plentiful supplies of free hydrogen and oxygen, which will burn together, and do two things in especial:—

I. They will produce saturated steam, powerful enough to account for the greatest effects of volcanoes and earthquakes.

II. The tremendous heat of hydrogen burning in oxygen is sufficient to account for the enormous heat evolved from active volcanoes, without involving science in the incredible and impossible dilemma—that the earth gives off annually an immense quantity of its *primitive* heat.

The present writer has generally omitted on former occasions, when quoting accounts of volcanoes in action, all mention of *Electricity*, not suspecting then what an important factor it is in volcanic operations. Notably so, in number 2 of the 78 evidences following. This deficiency is now amended. It is probable that others may have made similar omissions and will be on their guard against such in all future reports on volcanoes.

Since electricity holds so important a place in the

internal economy of active volcanoes, we must cease to wonder that there was a violent volcanic explosion at Vesuvius, and another in Java, in 1822 nearly at the same time. Just as we have ceased to wonder at the communication by electric wire between London and New York. The brilliant forked lightnings and loud roaring thunders of volcanoes are infinitely more powerful than the slender threads of electricity which pass along electric wires. And we need have no difficulty in accepting as a fact that the lightning of Vesuvius passed within the earth and became the lightning of Galangung in Java, in 1822.

Active volcanoes are *foci* of electric action on the grand scale.

When we consider forces so very great as heat which can only be measured by 14,541° Fahrenheit, and detonations so very loud that they can be heard at 742 English miles distance, we may feel quite sure that the earth contains within itself, at this moment, elements sufficiently powerful to account for the greatest effects of earthquakes and volcanoes; and that we should only be "travelling out of the record" if we looked *back* to the earth's primary heat, or *aside* to astronomical causes; which can only entangle us in difficulties and lead us astray.

The prodigious quantities of free heat and melted lava issuing from active volcanoes are in all probability not due to *primitive* heat, but to immense supplies of *newly created* heat, the products of hydrogen burning in

oxygen—those gases being abundantly supplied by frequent, powerful detonations of *volcanic* electricity, acting on the water present.

Humboldt gives in Bohn's 'Cosmos,' vol. v. pp. 274–5, a very interesting account of the aforesaid eruption of mountain Conseguina in 1835, which we quote at full length. He says:—"The volcano *Conseguina*, upon the cape which projects at the southern extremity of the Bay of Fonseca (lat. 12° 50′), is celebrated for the fearful eruption, preceded by earthquakes, of the 23rd January, 1835. The great darkness during the fall of ashes, similar to that which has sometimes been caused by the volcano Pichincha, lasted for 43 hours. At a distance of a few feet, firebrands could not be perceived. Respiration was obstructed, and a subterranean noise, like the discharge of heavy artillery, was heard not only in Balize in the peninsula of Yucatan, but also on the coast of Jamaica [which is 742 English miles distant*] and upon the plateau of Bogotá, in the latter case at an elevation of more than 8500 feet above the sea, and at a distance of nearly 560 geographical miles† (Juan Galindo, in Silliman's *American Journal*, vol. xxviii., 1835, pp. 332–6; Acosta, *Viages á los Andes*, 1849, p. 56, and Squier, vol. ii. pp. 110–3; Figures, pp. 163 and 165). Darwin (*Journal of Researches during the Voyage of the Beagle*, 1845, p. 291) calls attention to a remarkable coincidence of phenomena:—After a long

* Sound would travel this distance in 54 minutes.

† Sound would travel this distance in 50 minutes.

slumber, Conseguina in Central America, and Aconcagua and Corcovado (S. lat. 32¾° and 43½°) in Chili, broke out on the same day (accidentally?)." Darwin says, p. 291:—"On the night of the 19th of January, 1835, the volcano of Osorno was in action. At midnight the sentry observed something like a large star, which gradually increased in size till about 3 o'clock, when it presented a very magnificent spectacle. By the aid of a glass, dark objects, in constant succession, were seen, in the midst of a great glare of red light, to be thrown up and to fall down. The light was sufficient to cast on the water a long bright reflection. Large masses of molten matter seem very commonly to be cast out of the craters in this part of the Cordillera. I was assured that when the Corcovado is in eruption, great masses are projected upwards and are seen to burst in the air, assuming many fantastical forms, such as trees: their size must be immense, for they can be distinguished from the high land behind S. Carlos, which is no less than 93 miles from the Corcovado. In the morning the volcano became tranquil.

"I was surprised at hearing afterwards that Aconcagua, in Chili, 480 miles northwards, was in action on this same night; and still more surprised to hear, that the great eruption of Conseguina (2700 miles north of Aconcagua*), accompanied by an earthquake felt over 1000 miles, also occurred within six hours of this same time. This coincidence is the more remarkable as

* Darwin gives 480+2700=3180 geog. miles. 56° 20′=about 3380 m.

Conseguina had been dormant for 26 years; and Aconcagua most rarely shows any signs of action. It is difficult even to conjecture whether this coincidence was accidental or shows some subterranean connection. If Vesuvius, Etna, and Hecla in Iceland (all three relatively nearer each other than the corresponding points in South America) suddenly burst forth in eruption on the same night, the coincidence would be thought remarkable; but it is far more remarkable in this case, where the three events fall on the same great mountain chain, and where the vast plains along the entire eastern coast, and the upraised recent shells along more than 2000 miles on the western coast, show in how equable and connected a manner the elevatory forces have acted."

Mr. Darwin's difficulty can readily be explained by what has been said in the preceding pages. Subterranean electric action from one active volcano to another explains all. Everything appears to be on the grandest scale. Detonations so loud that they were heard at 742 English miles distance. Clouds of steam continuing to rise from Conseguina for months after. The explosive force of steam must necessarily have been of the most powerful character—which is fully accounted for by the enormous heat of hydrogen, burning in oxygen; caused by the plentiful decomposition of water by the grandest electric shocks. And accordingly we shall have good reason to believe presently that saturated steam may perhaps have, in very extreme

cases, as great a force as one million of tons per square inch.

No force is known but electricity which could have passed underground through 56 degrees of latitude, within 6 hours.*

SECTION VIII.

Volcano Vesuvius better known than any other—Sea water gets down to heated matter—Electricity, positive and negative, given out during volcanic activity—Hydrogen and oxygen given out from the crater—Whirlpool in sea near Vesuvius—Depression of water in Bay of Naples—Professor Palmieri, his observatory on Vesuvius—Observes watery vapour, sea-salt, sulphurous acid, and sulphuretted hydrogen issue from crater.

Infinitely more is known to science of the volcano Vesuvius, than of any of the volcanoes of Java; and it will therefore be for the reader's convenience that we should call his attention to some of the phenomena of the former volcano, before attempting to *calculate* (as we shall do presently) the total amount of force in tons per square inch which must have been in operation to produce the effects recorded in Appendix B.

* March 3, 1882.—Immediately on completing this sentence, I first received with great regret a notice of the death of Robert Mallet, Esq., F.R.S., F.G.S., M.R.I.A., my friendly opponent. Mr. Mallet always supported, as ably as he could, the opinions as to the cause of volcanoes and earthquakes, which he believed to be correct, and which differ from the views I am now advocating.—R. A. P.

We propose here to prove on credible testimony, (*a*) that sea-water gets down from the Bay of Naples to the heated matter beneath Vesuvius, that it is there converted into steam—necessarily saturated steam, because there is always plenty of water in the bay—that it issues as steam from the crater at the summit, and there deposits sea-salt all round;—(*b*) that electricity, both positive and negative, is given out during volcanic activity;—(*c*) that hydrogen gas [sulphuretted] is given out from the crater; and also oxygen, though not in such abundance as is yielded by common air. May not some oxygen have been used up by burning with hydrogen?

Articles 13 and 78 following are pieces of evidence of the connection of volcanic action with steam, collected by the present writer, and published by him in June 1866. The whole series are republished in the sequel.

13. In a recent eruption of Mount Vesuvius, aqueous vapour and storms of ashes issued. At Torre del Greco a sea whirlpool of 360 ft. diameter was boiling violently, and emitted a strong sulphurous odour: the sounding was 23 fathoms. The principal development was carbonic acid gas.—*Morning Advertiser*, Dec. 28, 1861.

78. ". . . . . Then all round Vesuvius, extending even to Castellamare, there is a perfect dearth of water; so much so that the arsenal of that place, which has always derived its water from mountain springs, that have never failed even in summer, is now compelled to

send to a considerable distance for water. Perhaps the most startling fact is the depression of the sea all round the bay. I have examined it at various places, and find that this depression is at least two palms [fully 20 English inches*] beneath the ordinary level. We have certainly had a month's calm weather, but still this is scarcely sufficient to account for the fact now stated." —*British Press* (Jersey), Jan. 12, 1866.

And then the present writer adds a query of his own:—"Is the water sinking down to the melted lava?"

Professor Palmieri, who has studied Vesuvius for many years, and has an observatory upon it—speaking of the eruptions of 1872—says, p. 117:—

"As to the gaseous emanations of fumaroles, watery vapour with few exceptions comes first; this conveys the material which first appears in the sublimations, viz. sea-salt, and for the most part oxide of copper . . . . . Sulphurous acid follows hydrochloric at a later period, and sulphuretted hydrogen occasionally succeeds.

"Having examined the gases of fumaroles by means of a graduated tube and the pyrogallate of potash, I

* It is stated in Beardmore's Hydraulic Tables 1852, p. 36, that a Naples palm is 10·38 English inches. Two palms, or fully twenty inches, is a *perceptible* quantity in the Bay of Naples, where the total rise of tide is only about two English feet, especially with a calm sea. Some find it impossible to believe that sea-water can descend as here described. The present writer is not careful to argue this point. He accepts the statement of Professor Palmieri—who certainly knows more about events at Vesuvius than any other person whatever—that sea-salt, with all which it contains, issues from the fumaroles.—R. A. P.

always found that it contained less oxygen than the surrounding atmosphere." *

The presence of "sea-salt" seems to be a proof positive that it must have come from the Bay of Naples. He says at p. 121 :—"Even chloride of iron, which was so abundant in the lavas, was scarcely perceptible in the smoke, which almost exclusively deposited sea-salt on the surrounding rocks; I say sea-salt advisedly, and not chloride of sodium, to show that I include all that sea-salt contains."

At p. 123 he perceives sulphuretted *hydrogen* and *pure aqueous vapour* issuing from the fumaroles :—"The fumaroles were almost all on the brims of the craters, with emanations of hydrochloric and sulphurous acid; in a few that were removed from the brim, sulphuretted hydrogen was perceptible.

* * * * * *

"In some fumaroles, where I perceived the smell of sulphuretted hydrogen, I found sublimed sulphur under the scoriæ. At the source of the lava stream that flowed towards the Camaldoli, on the seaward flank of Vesuvius, I observed large fumaroles of steam only, pure aqueous vapour."

Thus the steam was seen on the "seaward flank," as might have been expected, as it came from the sea.

* 'The Eruption of Vesuvius in 1872, by Professor Luigi Palmieri, of the University of Naples, Director of the Vesuvian Observatory. With Notes and an Introductory Sketch of the Present State of Knowledge of Terrestrial Vulcanicity, the Cosmical Nature and Relations of Volcanoes and Earthquakes, by Robert Mallet, Mem. Inst. C.E., F.R.S., F.G.S., M.R.I.A., &c., &c., with illustrations. 1873.'

In p. 125 et seq. he copiously describes the instruments in his observatory on Vesuvius, and gives plates of them; amongst others is his "Bifilar Electrometer," with which we are principally concerned at the present moment, as we are about to quote his account of the electricity of Vesuvius.

Professor Palmieri on Vesuvius, pp. 130–4.

With smoke, without ashes, he obtained strong positive electricity—with ashes only, strong negative electricity—same phenomena observed when lightning flashed—flashes are always derived from midst of smoke, accompanied with ashes and lapilli—he thinks greater part of electricity proceeds from rapid condensation of vapours—condensation of vapours the origin of the positive electricity—electric tension of smoke increased by descent of ashes and lapilli—lightnings of Vesuvius not accompanied by rain, but induced by descent of ashes and lapilli.

At p. 138 is given the 18th of his general conclusions, as follows:—

"18. The smoke gives positive electricity, and the falling ashes negative electricity."

SECTION IX.

Everything connected with volcanoes and earthquakes can be accounted for by terrestrial forces—Rev. John Michell's account of tremendous effects of about a gallon of water, converted into steam by heat of 1869° Fahr.

Terrestrial forces of the present day will apparently account for everything connected with volcanoes and earthquakes, as we have endeavoured to prove: without having recourse to prehistoric or astronomic causes. If we may not suppose these terrestrial forces to be employed in the manner we have endeavoured to sketch in the foregoing pages, we shall certainly be in a difficulty how else to dispose of the several enormous forces in action, by finding work for them to do and account for.

Some readers find it difficult to believe that saturated steam has so great a force as it really has when heated to a very high temperature. The Rev. John Michell states* that "At the casting of two brass cannon at Windmill-hill, Moorfields, the heat of the metal of the first gun drove so much damp air into the mould of the second, which was near it, that as soon as the metal was let into it, it blew up with the greatest violence, tearing up the ground some feet deep, breaking down the furnace, untiling the house, killing many spectators on the spot with the streams of melted metal, and scalding many others in the most miserable manner."

* Phil. Trans. R. S., vol. ii., 1760, p. 458.

Professor Daniell, F.R.S., gives 1869° F. as the temperature at which brass melts. And for reasons which will be stated in the sequel, we have reason to believe that saturated steam of that temperature would have a force of about 114 tons per square inch. The total quantity of water employed in this catastrophe was so little that it is called merely "*damp*"; it probably was not more than a gallon; if so, it would weigh only 10 lb.

SECTION X.

Author's personal experience of immense resistance of atmosphere—In October 1822, Mount Galangung propelled solids 40 geographical miles, or fully 46 English miles.

Some forty years ago, the present writer had a little personal experience of the great resistance of the atmosphere to a body moving rapidly through it. Having on a Macintosh cloak, and being mounted on a thoroughbred horse, he was riding along a good, wide, straight road. The cloak cracked and rattled, the horse took fright, and galloped along the road at the top of his speed; and the rider had the greatest difficulty in keeping in his position, and in avoiding being carried backwards over the horse's tail. He stood in the stirrups, grasping the horse's sides with all the strength of his knees, and stooping forward so that his head and

body were nearly at right angles to his lower limbs. This effected two things; namely, it opposed the weight of his body and head to the backward action of the air, and it exposed as few square feet of the head and body as possible to the resistance of the atmosphere. Nevertheless, all the strength and determination he possessed were absolutely necessary to maintain his position. The strain upon every part of the front of his person was very great, and he was sore and stiff for a week after. After thus galloping a mile or two, the horse slackened his speed of his own accord, and the difficulty was at an end. But the writer can never forget the great resistance of the air to the rapid motion of a body through it, and will now attempt to make an approximate, moderate calculation of the resistance of the atmosphere to the motion through it of some lapilli of the size of nuts, which were propelled by volcanic action from Mount Galangung, in October 1822 (as stated in Appendix B), to beyond the river Tandui, "which is 40 miles distant!" This distance is so very great and unprecedented, that though Sir Charles Lyell was a very careful man, and of course a highly distinguished geologist, and repeats this remarkable statement both in the 10th, 11th, and 12th editions of his 'Principles of Geology,' it seemed absolutely necessary to verify his statements, which the present writer accordingly did at the British Museum Library.

SECTION XI.

British Museum, large scale chart of Isle of Java—Shows Mount Galangung and river Tandui 40 geographical miles apart—Lapilli projected all that distance by saturated steam of volcano.

British Museum Library, March, 1882.

Examined a large scale chart of the Isle of Java,* scale about 8·85 English inches to a degree of 60 nautical, or geographical miles of 6075·6 English feet each, measured along the curvature of the earth at sea-level. This chart shows all the principal features of the island, but contains no names. There is however at the right hand top corner an index map, on which appear many names. Amongst the rest Guntur Galungung, meaning Mount Galangung; and Tji Tandui, meaning River Tandui; consequently it is easy to identify these on the main chart. River Tandui runs into the sea on the south coast, which it enters at right angles. Mount Galangung is 40 nautical or geographical miles from the river, consequently there cannot be a doubt that the lapilli were propelled to a distance of 40 miles by the volcanic force, and Sir Charles Lyell's statement is quite correct. No one knows, or ever can know, at what angle with the

* 'Schoolkaart van Java door Jonkheer J. F. W. von Schmidt auf Altenstadt Kontrolleur, 1e. classe, bÿ het Binnenlandsch Bestuur op Java. . . . Schaal van 1 : 478,000. 1875.' 1 : 2,390,000 scale of index map.

horizon the lapilli were projected. They must have described a *paraboliform* curve in the air, the dimensions of which can never be discovered. We must therefore calculate from the horizontal distance, which is less than the length of the paraboliform curve, and therefore *within* the truth.

We have nowhere been able to discover the height of Mount Galangung above the sea; but De Buch, on p. 426, gives the height of Gunung Guntur, a similar and neighbouring volcanic mountain, 5710 Paris feet (= 6081 English feet), and the best we can do is to suppose Galangung about the same, say 6000 English feet, and take as the average, atmospheric pressure at 3000 feet, or half the height; which having regard to the observations of Mr. James Glaisher, F.R.S., on his ninth balloon ascent (Brit. Assn. Report, 1863) gives the average atmospheric pressure overcome by the lapilli in October, 1822, as 13·378 lb. per square inch for every inch of the 40 geographical miles.

SECTION XII.

Approximate calculations—to propel the lapilli

	TONS.	
40 geographical miles required	117·72	per sq. in.
40 geographical miles' atmospheric resistance	17,417	,,
	17,534	,,

This force must have been exceeded—From Galangung to Tandui is from west to east, prevalent wind is from south to north; therefore, no help from wind—Diagram showing distance and relative positions of Vesuvius and Galangung—Eruptions at both in October 1822, though 6315 geographical miles apart—Van der Boon Mesch proves terrible lightnings and thunders at Galangung in October 1822—Sir W. Hamilton and Palmieri both prove power and activity of underground lightning at Vesuvius—Electricity famous for passing underground thousands of miles in very short time; therefore Vesuvius and Galangung must have communicated with each other—Dr. Carl Scherzer proves regularity of intervals between detonations of underground lightning, and their continual repetition, at Conseguina in Central America, January 1835—Thunder was heard from Conseguina to Jamaica [742 English miles], in January 1835, Humboldt states.

Approximate Calculation of the Weight of the Lapilli "the Size of Nuts."—Four hundred and seventy-seven "cob nuts," which are nearly round, were filled into a cylindrical vessel, 6 inches high and 4¼ inches diameter, and occupying 85·116 cubic inches. These represented the lapilli, and are supposed to have had a sp. gr. of 2½, water being 1; and weighing 7·6964 lb. The 85·116 cubic inches are for an obvious reason supposed to be lineally placed.

c. in. lb. lin. in. lb. tons weight.
85·116 : 7·6964 :: 2,916,288 (40 geog. miles) : 263,698 = 117·72

lin. in. lb.
40 geog. m. = 2,916,288 × 13·378* = $\frac{39,014,100}{2240}$ = 17,417

Explosive force of Mount Galangung per sq. in. 17,534 tons.

But for two reasons the force must have been more than 17,534 tons per sq. inch, viz. first, the lapilli were projected "*beyond* the river Tandui, which is 40 miles distant." And second, on October 12, a second eruption occurred "more violent than the first." See Appendix B. And we have made no allowance for the extra length of the paraboliform curve.

Mount Galangung is on the west, and the river Tandui on the east; consequently the lapilli were propelled from west to east. And that the wind did not assist to drift them is capable of the most direct proof, which will now be given.

It is stated in the 8th edition of Encyc. Brit., Art. "Meteorology," p. 649, "(7.) In the tropical regions, where the superficial air always flows toward the equator," &c.—Consequently, whatever amount of wind there was, blew from south to north at Galangung—that is, at right angles to the direction in which the lapilli were flying; and they cannot have received the least help in their flight from the wind.

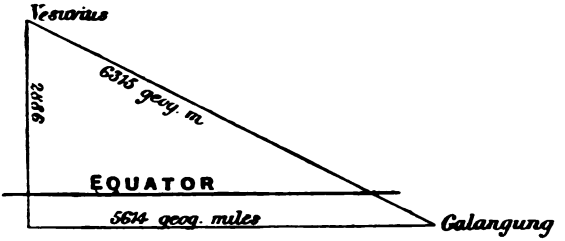
In Dr. Butler's Atlas, the Index states that

Vesuvius is in Latitude .. 40° 52′ N.
„ Longitude .. 14° 26′ E.

* Pressure of air per square inch at 3000 feet high, the supposed half height of Mount Galangung.

Schmidt's chart gives:—

Mount Galangung, Latitude, 7° 14′ S.; Longitude, 108° 0′ E.



There is, of course, no wire laid direct between Vesuvius and Galangung, and the forward transmission of the very powerful electric shocks must be through the earth, and the return, to complete the circuit, must be through the earth also.*

Java runs nearly due east and west, and its

West end is in 105° E. long. East end is in 114¼° E. long.

Its whole length being 570 geog. miles.

Galangung is about the centre, between the north and south coasts.

There was an eruption of Vesuvius in October 1822, during the space of more than 20 days,† when violent explosions threw out all the accumulated mass from the crater, so as to leave an immense chasm about 3 miles in circumference. "It measured at first according to

* The wire from London to New York communicates with the earth at both ends, and when a telegram is sent from the former to the latter the electricity returns through the earth from the latter to the former to complete the circuit. Without this completion there could be no telegram.

† Lyell's 'Principles of Geology,' ed. 10, vol. i. p. 620. He quotes Scrope.

the account of some authors 2000 feet in depth from the extreme part of the existing summit; but Mr. Scrope, when he saw it soon after the eruption, estimated its depth at less than half that amount."

An account is given in Appendix C, quoted from Boon Mesch, of the explosions of Galangung in the same month, October 1822, and of the "terrible lightnings and thunders." Sir W. Hamilton and Palmieri have both sufficiently proved the power and activity of underground thunder and lightning at Vesuvius, and we may feel quite sure there is communication between Vesuvius and Galangung. Electricity is *famous* for passing underground through hundreds and thousands of miles in short spaces of time. And accordingly it must have passed through the 6315 miles in October 1822, decomposing water into hydrogen and oxygen, which, burning together, produced saturated steam of the greatest power.

We have saved the following paragraph, purposely to introduce it to the reader in this place:—

Travels in the Free States of Central America, by Dr. Carl Scherzer, vol. ii. p. 227. Longmans, 1857. Scherzer says:—"The regularity of the intervals between the detonations, and their continual repetition,* soon made it evident that the thunder did not proceed from the electrical discharges of clouds in a high region of the atmosphere, but from below in the bowels of the earth."

* At Conseguina, in January, 1835.

It measures 742 statute miles (or 18 inches) from Conseguina to the west end of Jamaica, on 'Monk's New Map of Central America, &c. Compiled from the latest Government Maps and other authentic sources, 1857.' "And a subterranean noise, like the discharge of heavy artillery," was heard all this distance, Humboldt says, vol. v. p. 275, Bohn's 'Cosmos.'

SECTION XIII.

Chemical Analyses of Water, Air, and Vitriol, by Professor Fownes—Water is decomposed by shocks of electricity into its constituent gases, pure hydrogen and pure oxygen, the middle portions of the liquid remaining apparently unaltered—Great importance of these unaltered portions—From them saturated steam is produced, temperature 14,541° Fahr., and consequently enormously powerful —Water, as Mr. Grove has shown, is also decomposed into its constituents by heat—Without electricity, heat will give us our hydrogen and oxygen; and consequently our saturated steam and volcanic explosions—Liebig's method of collecting oxygen—Nature mixes air with hydrogen in volcanoes, and passes electricity through the mixture, producing oxygen abundantly; thus we obtain abundance of hydrogen and oxygen, which burning together give us our most powerful saturated steam—Manufacture of vitriol.

*Chemical Analyses of Water, Air, and Vitriol of Commerce.**

The following extracts from Professor Fownes' very valuable work are germane to the matters we have on hand in this extract.

* From a 'Manual of Elementary Chemistry,' by George Fownes F.R.S., 10th ed., edited by H. Bence Jones, 1868. John Churchill and Sons.

Water.—"It appears that the composition of water was first demonstrated in 1781 by Cavendish (or by James Watt), but the discovery of the exact proportions in which oxygen and hydrogen unite in generating that most important compound has, from time to time to the present day, occupied the attention of some of the most distinguished cultivators of chemical science.

* * * * * *

"The decomposition of water may be effected by voltaic electricity. When water is acidulated so as to render it a conductor,* and a portion interposed between a pair of platinum plates connected with the extremities of a voltaic apparatus of moderate power, decomposition of the liquid takes place in a very interesting manner: oxygen in a state of perfect purity is evolved from the water in contact with the plate belonging to the copper end of the battery, and hydrogen, equally pure, is disengaged at the plate connected with the zinc extremity, the middle portions of liquid remaining apparently unaltered."—These "unaltered" portions of water are of the utmost importance in volcanoes. It is from them that the *saturated steam* is produced having a temperature of more than 14,000 degrees Fahr. by means of the hydrogen burning in oxygen—and consequently enormously powerful.—To proceed with our quotation:—

"By placing small graduated jars over the platinum plates, the gases can be collected and their quantities

* See Prof. Fownes' section on Electro-chemical Decomposition.

determined ..... were it not for the accidental circumstance of oxygen being sensibly more soluble in water than hydrogen, the proportion of 2 to 1 by measure would come out exactly.

"Water, as Mr. Grove has shown, is likewise decomposed into its constituents by heat."

If all electricity has vanished for the time being, we may still have our two gases to give out very high temperature and produce very powerful saturated steam—if only the electricity, when it vanishes, chances to leave heat behind it. To go on with our quotation:—

"The effect is produced by introducing platinum balls, ignited by electricity or other means, into water or steam. The two gases are obtained in very small quantities at a time."

Yes undoubtedly—the quantities are very small, with a chemist's very small apparatus. But on Nature's grand scale, with her grand appliances, the quantities will be very great.

P. 269.—"When a pair of platinum plates are plunged into a glass of water to which a few drops of oil of vitriol have been added, and the plates continued by wires with the extremities of an active battery, oxygen is disengaged at the positive electrode, and hydrogen at the negative, in the proportion of one measure of the former to two of the latter, nearly."

Analysis of Air.—"An analysis of air is very well effected by passing it over finely divided copper, contained in a tube of hard glass, carefully weighed, and

then heated to redness. The nitrogen is suffered to flow into an exhausted glass globe, also previously weighed. The increase of weight after the experiment gives the information sought.

* * * * * *

"Liebig has proposed to use an alkaline solution of pyrogallic acid (a substance which will be described in the department of organic chemistry) for the absorption of oxygen. The absorptive power of such a solution, which turns deep black on coming into contact with the oxygen, is very considerable. Liebig's method combines great accuracy with unusual facility and rapidity of execution."

Nature, no doubt, often conducts the following experiment for herself, on the grand scale, in active volcanoes: all the components are evidently present. "Another plan is to mix the air with hydrogen, and pass an electric spark through the mixture: after explosion the volume is read off and compared with that of the air employed." He then describes the process in detail.

Manufacture of the Oil of Vitriol of Commerce.

The present writer has often seen this process, at Altham, near Accrington, in East Lancashire. It is conducted exactly as Professor Fownes describes below:—

"A large and very strong chamber is built of sheet lead, supported by timber framing; on the outside, at one extremity, a small furnace or oven is constructed,

having a wide tube leading into the chamber. In this sulphur is kept burning, the flame of which heats a crucible containing a mixture of nitre and oil of vitriol. A shallow stratum of water occupies the floor of the chamber, and a jet of steam is also introduced. Lastly, an exit is provided at the remote end of the chamber for the spent and useless gases. The effect of these arrangements is to cause a constant supply of sulphurous oxide, atmospheric air, nitric acid, vapour, and water in the state of steam, to be thrown into the chamber, there to mix and react upon each other."

SECTION XIV.

How nature makes vitriol—Thirty-eight volcanoes in Java—Crater of Taschem contains a lake strongly impregnated with sulphuric acid—Poison valley, half mile in circumference, every living thing entering is killed by carbonic acid gas—Near volcano Talaga Bodas sulphureous exhalations have killed many animals—Vesuvius in October 1822, by Professor Phillips.

How Nature Manufactures Oil of Vitriol.

"There are said to be thirty-eight considerable volcanoes in Java, some of which are more than 10,000 feet high. They are remarkable for the quantity of sulphur and sulphureous vapours which they discharge. They rarely emit lava, but rivers of mud issue from them, like the Moya of the Andes of Quito. The memorable eruption of Galangung is described [in Appendix B of this Tract]. The crater of Taschem, at the

eastern extremity of Java, contains a lake strongly impregnated with sulphuric acid, a quarter of a mile long, from which a river of acid water issues, which supports no living creature, nor can fish live in the sea near its confluence. There is an extinct crater near Batur, called Guevo Upas, or the Valley of Poison, about half a mile in circumference, which is justly an object of terror to the inhabitants of the country. Every living being which penetrates into this valley falls down dead, and the soil is covered with the carcasses of tigers, deer, birds, and even the bones of men; all killed by the abundant emanations of carbonic acid gas by which the bottom of the valley is filled.

"In another crater in this land of wonders, near the volcano of Talaga Bodas, we learn from Mr. Reinwardt, that the sulphureous exhalations have killed tigers, birds, and innumerable insects, and the soft parts of these animals, such as fibres, muscles, nails, hair, and skin, are very well preserved, while the bones are corroded and entirely destroyed."—Lyell's *Principles of Geology*, 10th ed. vol. i. p. 589.

Vesuvius in October 1822.—"Heavy rains fell from the volcanic clouds. . . . After the eruption, the mountain was found greatly changed in aspect; the Vesuvian cone was lost; a huge crater three miles in circumference, with steep interior faces, occupied its place, and was partially filled by vapour of water mixed with hydrosulphuric and hydrochloric acids."—*Vesuvius*, by Phillips, p. 102.

SECTION XV.

Projection of lapilli 40 miles not unique; on the contrary, Vesuvius in 1779 projected stones and scoriæ of greater weight, viz. 1 or 2 ounces, 30 miles—We cannot convert distance at which thunder can be heard (say 742 English miles) into tons of force per square inch, but it must necessarily have been very powerful, and must have decomposed water into large quantities of hydrogen and oxygen, these in turn producing saturated steam of *maximum* power—Cotopaxi has propelled rocks of 100 cubic yards or 200 tons, 8 or 9 miles—This required a force of 2625 tons per square inch—Prevalent wind in tropics is towards the equator.

The astonishing force of at least 17,534 tons per square inch operating at Galangung in October 1822 was evidently due to saturated steam, as any one reading carefully the first paragraph of Appendix B cannot fail to perceive. This however is not an isolated, solitary, instance of steam power of similar magnitude. By no means. On the contrary, Vesuvius operated with pretty much the same degree of power in August 1779. For although "the smaller stones and scoriæ" were only propelled 30 miles instead of 40, yet on the other hand they were larger, being one or two ounces in weight, while the lapilli of Galangung only averaged about a quarter of an ounce each, as it took 477 of them to weigh 7·6964 lb. The force at Vesuvius in 1779 can scarcely have been less than 17,534 tons per square inch.

Vesuvius in 1779.—"Even to distances of 30 miles, at Benevento, Foggia, and Monte Mileto, the smaller stones and scoriæ were carried in abundance, one or two

ounces in weight; while nearer the mountain, masses thirty pounds in weight crushed in the roof of Cacciabella, a hunting seat of Neapolitan royalty, and farther off, even at Manfredonia, 100 miles away, minute ashes fell thick. This was in the eruption of the 8th of August [1779], and it was computed that the shower of dust had travelled 100 miles in two hours, though the wind was not observed to be strong."—*Vesuvius*, by Phillips, p. 86.

Conseguina.—There are not sufficient data existing to enable us to convert the operations of Conseguina into tons force per square inch. We can only get at the subject indirectly. In this way. Underground thunder and lightning, so very loud that the detonations can be heard at 742 English miles distance, must necessarily have been very powerful. And the shocks must have decomposed large quantities of water into its constituent gases, oxygen and hydrogen. These, burning together, necessarily converted whatever other water was present into saturated steam; great in quantity and very great in power. Its force in tons must have been of kindred magnitude to the respective forces of Galangung in 1822 and of Vesuvius in 1779.

Cotopaxi.—"The volcano of Cotopaxi has been known to throw out, to the distance of eight or nine miles, a mass of rock about 100 cubic yards in volume." —Lyell's *Principles of Geology*, ed. 10, vol. ii. p. 223.

One hundred cubic yards of granite would weigh 200 tons. Its weight is 13½ cubic feet to a ton.

This, if we have made no mistake in calculating, required a force of 2625 tons per square inch, for a horizontal distance of nine English miles, to overcome the *resistance of the air only;* which we reckon at 10·314 lb. to the square inch. Assuming barometric pressure at 20·94 inches for a height of 9609 feet (which we take to be about half the height of Cotopaxi), and then using the following form:—

29·905 in. bar. : 14·7304 lb. :: 20·94 in. bar. : 10·314 lb.*

The 20·94 ins. bar. for 9609 feet high are obtained from Mr. James Glaisher's ninth balloon descent.—*Brit. Assn. Report,* 1863.

Direction of Wind in the Tropics.—The heat of the sun at the equator causes the air to ascend there. And near the surface of the earth cooler air necessarily rushes in to supply its place, both from the north and from the south. We gave an illustration of this (quoted from the Encyc. Brit.) in Section XII., when treating of Galangung. See Herschel's 'Outlines of Astronomy,' 7th ed., pp. 150–1 especially.†

* When the barometer is at 29·905, distilled water boils at 212°, at 62° F. at sea level, the mean barometric pressure being per square inch 14·7304 lb. These facts are well known.

† Sir John Herschel here corroborates the fact that breezes as a rule blow towards the equator in the tropics.

SECTION XVI.

Great earthquake of Lisbon shook nearly $\frac{1}{13}$ of whole surface of globe; how deeply no one knows—17,534 tons per square inch must have been the merest trifle in comparison—Regnault's experiments lead to belief that pressure of saturated steam increases as 4·5 power of temperature; if so, 14,541° Fahr. would give about 1 million of tons per square inch.

The great Earthquake of Lisbon, November 1st, 1755.

On this occasion 14,600,000 square miles, or nearly $\frac{1}{13}$ of the whole surface of the globe was shaken. But no man knows, or can form even the roughest estimate, *what was the depth* to which the land and sea were shaken—how many hundreds or thousands of feet deep. So that it would be quite in vain to attempt to calculate the *total force* in tons operating. Of one thing we may be certain, however, viz., that the pressure of the atmosphere at sea level averages alone 14·7304 lb. per square inch.

It is perfectly clear that the force of 17,534 tons per square inch, operating at Mount Galangung, was the merest trifle in comparison to the whole thickness of earth and sea shaken.

By the calculation given in Appendix A, taking the pressure of the saturated steam to increase as the 4·5 power of the temperature—and there is no reason why it should not do so—we get 1,132,810 tons per square inch for the 14,541° Fahr., the modification

having diminished down to a single unit; leaving us the net, simple law:—

The pressure of saturated steam when the temperature exceeds 285° Fahr. increases as the 4·5 power of the temperature.

SECTION XVII.

Rev. John Michell first proposed steam the motive power in volcanoes and earthquakes—Drs. Hutton, Shaw, and Pearson appear to have thought highly of his paper in Phil. Trans. R.S.—He was a gentleman of unusual ability—He invented the torsion-balance—Herschel determined weight of earth with it, and content in cubic miles 259,378 millions, forming a vast reservoir of water and electricity—Shocks of the latter decompose portions of former into hydrogen and oxygen—These burn together, giving out greatest terrestrial heat known to man; this converts water into proportionally powerful steam—This steam causes volcanoes and earthquakes, for how is it possible so very vast a power can remain idle?—Whole mass of artificial explosives trifling in comparison—Michell's views—He thinks depth shaken by great Lisbon earthquake could not be much less than 1 or 1½ miles, or exceeding 3 miles—Graphic description of later Lisbon earthquakes—Motion of shocks directly up and down, which is apparently consistent with a steam explosion—Dreadful underground groans due to thunder.

The Rev. John Michell was, we believe, the first to advance the proposition that *steam is the motive power* in earthquakes and volcanoes. He read a copious, well-developed paper in 1760 to the Royal Society on the subject, referring particularly to the great earthquake of Lisbon, November 1, 1755. Of this paper Doctors Hutton, Shaw, and Pearson, who edited the Transac-

tions, appear to have thought so favourably, that though they have abridged it somewhat, they have yet devoted to it fully 24 quarto pages of their very valuable space in vol. xi. Michell himself was a gentleman of more than usual ability among the Fellows of the Royal Society. Among other things he did, he invented the torsion balance. "Cavendish expressly states that Michell's invention of this beautiful instrument, and his communication of it to him, was antecedent to the publication of Coulomb's researches.*—*Phil. Trans.* 1798, page 469." This instrument it was, by means of which Cavendish, Reich, and Bailey were enabled to determine that the average specific gravity of the whole earth is about $5\frac{1}{2}$, fresh water being 1. Sir John Herschel hereby gave his determination of the whole weight of the earth in tons. He also gives the earth's solid content in cubic miles as 259,373 millions.† All these hundreds of thousands of millions of miles form a vast reservoir of water and electricity. The electricity by its shocks decomposes portions of the water into its constituent gases, hydrogen and oxygen; these burning together produce the hottest flame known on or in the earth; this flame in turn converts other water into saturated steam powerful in proportion to the greatness of its heat. This steam *necessarily* causes earthquakes and volcanoes; for how is it possible so very vast a power can remain idle?

All the guncotton, gunpowder, dynamite; all the

* 'Outlines of Astronomy,' 7th ed., p. 557. † Ibid., p. 560.

fulminates and whatever other artificial explosives may exist; are infinitely small compared with the whole bulk of the earth. The whole mass of them now existing might be packed up in the portmanteaus of the adult male inhabitants of the earth. The crushing of rocks is also infinitely small by comparison, and it is not an explosive force at all. Except so far as this—the rocks themselves are actually blown up and crushed by the saturated steam in active volcanoes.

In vol. xi. Phil. Trans. R.S. 1760, p. 458, the Rev. John Michell states as follows:—"If we suppose that these vapours, when pent up, are the cause of earthquakes, we must naturally expect that the most extensive should take their rise from the level and low countries; but more especially from the sea, which is nothing else than waters covering such countries; accordingly we find the great earthquake of November 1, 1755, which was felt at places near 3000 miles distant from each other, took its rise from under the sea; as is manifest from that wave which accompanied it. The same thing is to be understood of the earthquake that destroyed Lima in the year 1746, which, it has been said, was felt as far as Jamaica;* and as it was more violent than the Lisbon earthquake, so, if this be true, it must probably have been more extensive also. There have been other very extensive earthquakes in South

* This is 2120 English miles, and we suppose it extended as far in the opposite direction, namely south of Lima: total, 4240 English miles. —R. A. P.

America. Acosta says, they have been often known to extend themselves 100, 200, or 300, and some even 500 leagues along the coast. These have been generally, if not always, attended with waves from the sea.

"Mr. Michell having said before, that he imagined earthquakes were caused by vapours raised from waters suddenly let out upon the subterranean fires, does not easily find any other cause capable of producing such sudden and violent effects, or of raising such an amazing quantity of vapour in so small a time. That the blasts discharged from volcanoes are always produced from it is highly probable; that they are often so cannot admit of the least doubt. There can be no doubt that considerable quantities of water must be often let out upon the fires of these volcanoes, and whenever this happens it will be immediately raised by their heat into a vapour whose elastic force is capable of producing the most violent effects."

He then relates the catastrophe which we have quoted in Section IX., of casting two brass cannon, and the dreadful effects caused by the sudden conversion of perhaps no more than a single gallon of water into saturated steam at the high temperature of 1869° Fahr.

Ibid. p. 472.—Michell considers the important question—*at what depth was the focus* of the great Lisbon earthquake? and concludes as follows:—

"As the observations relating to the earthquake of November 1, 1755, are too gross, it would be in vain

to attempt, by any of the foregoing methods, to determine, with any certainty, the depth at which the cause of it lay; but if Mr. Michell might be allowed to form a random guess about it, he would suppose (on a comparison of all circumstances) that it could not be much less than a mile or a mile and a half, and he thinks it is probable it did not exceed 3 miles."

Ibid. p. 541.—We quote the two following paragraphs for the sake of the graphic descriptions of the *modus operandi.*

"*An account of the earthquake at Lisbon, March* 31, 1761, *in a letter from thence, dated April* 21, 1761.

"This earthquake happened the 31st, precisely at 12 o'clock, and lasted full five minutes, with a smart and equal vibration. It exceeded all the others except that of Nov. 1, 1755. It was attended with no other consequences but that of alarming the inhabitants, throwing down some ruins, and rending some houses. About 1¼ hours afterwards, the sea began to flow and ebb, about 8 feet perpendicular, every 6 minutes, and continued till night. Some small shocks were felt before and after, but of no moment."

"*Another account of the same earthquake: in a letter from Mr. Molloy, dated there, April* 3, 1761.

"In this letter there are but few additional circumstances. The shock seemed to Mr. Molloy to spring from the bowels of the earth, and the motion to be directly up and down. It is the general opinion that if it had run from west to east, or from any quarter of

the globe to the other as the great one of the 1st Nov. 1755, did, there would not have been a house left standing in this unfortunate place; as all the gentlemen that reside here say, it was more severe and constant for the time than the former. Many buildings have tumbled down, but few people were killed. The earth groaned in so dreadful a manner, that we expected every moment it would open, and swallow this place and all its inhabitants . . . . ."

There are two remarkable things in this letter.—*First*, " the motion directly up and down " appears to be exactly what would be due to a steam explosion of sufficient power beneath the town.

And *second*, the dreadful groans underground were no doubt due to the thunder of electricity.

SECTION XVIII.

Conclusions.

Underground lightning communicated from Vesuvius to Galangung—The force at each volcano being about equally, and very, great, it follows that probably one and the same *quantum* of electricity operated in both mountains—The like at Conseguina and the South American volcanoes named—The many detonations each decomposed a quantity of water into its constituent gases, pure hydrogen and pure oxygen—These burnt together, giving out a temperature of 14,541° Fahr. in large quantities—This converted water into saturated steam which may have had a force of 1 million of tons per square inch—When the force of steam exceeds the strength of the weakest part of the containing cavity, explosion necessarily follows—Saturated steam the greatest terrestrial force known—Some such sublime force required to account for the

effects of the great Lisbon earthquake—Melted lava of volcanoes probably not due to primitive heat, but to newly created heat of hydrogen burning in oxygen—Because the enormous heat must necessarily have melted all rocks, earths, and metals, at hand—Secular refrigeration at best of doubtful existence—Examples of water getting down to volcanic foci—Disbelief in the enormous power of saturated steam—Strength of great guns is trifling in comparison.

Active volcanoes often communicate with each other at immense distances, by means of underground thunder and lightning.

The presence of *underground* lightning was seen, and its thunder heard, at Vesuvius by Sir William Hamilton three generations ago. And the like were seen and heard by Van der Boon Mesch and others at Galangung in October 1822; and in the month of October 1822 by Scrope and others at Vesuvius. And the violence of Galangung and Vesuvius on that occasion was, in each case, about equally, and very, great; which leaves no doubt that the operating force was one and the same.—Dr. Charles Scherzer bears testimony to the presence of underground thunder and lightning at Conseguina in January 1835, and Charles Darwin testifies to what appears to be their presence at more than 3000 miles distance (within 6 hours) at Aconcagua and Corcovado. Every one knows the extreme facility with which electricity passes through spaces of several thousands of miles in exceedingly brief spaces of time. But we believe no one has *perceived* the actual part which electricity performs in volcanoes and earthquakes until now. It is no figure of speech,

but a simple truth and a matter of fact, when we affirm —as we do at this moment—that in October 1822, Vesuvius communicated with Mount Galangung, 6315 geographical miles; and that in January 1835, Conseguina communicated *also* by means of subterranean thunder and lightning 3380 miles, with the South American volcanoes named: that in each case there were many detonations; every detonation decomposed a portion of water (perhaps of air also) into its constituent gases, pure hydrogen and pure oxygen: that these burnt together, causing the highest temperature belonging to the earth, namely 14,541° Fahr., in large quantities: that large quantities of water were at the same time left apparently unaltered; and were converted by the heat into saturated steam of the highest temperature and greatest power—causing volcanic action. And there appears, in "the nature of things," to be no limit to the magnitude of the pressure which will be obtained, by crowding (by the heat), into the cavity, of more, and more, and still more steam as the temperature of the steam gradually increases, until the enormously great pressure due to 14,541° Fahr. has been reached. When the power of resistance of the immensely thick masses of rocks and earths which form the cavity has been exceeded, an explosion necessarily takes place at the weakest point. We have given reasons in Appendix A for believing that the *maximum* force is about 1 million of tons per square inch, assuming the pressure to increase (above 285° Fahr.) as the 4·5 power of the

temperature. *There is no other terrestrial force at all approaching to saturated steam in power and magnitude.* Some such sublime force is required, to account for the effects of the great Lisbon earthquakes.

The melted lava of volcanoes is not due to primitive heat, but to the newly created heat of hydrogen burning in oxygen.

Pure hydrogen burning in pure oxygen on the grand scale in active volcanoes has a heat so immense, that it necessarily melts all the solids, such as rocks, earths, and metals, which are exposed to its action. Consequently it is clear that the immense quantities of melted lava which often issue from active volcanoes are not due to *primitive* heat, but consist of *newly melted* matter. On a former occasion the present writer attributed modern melted lava to primitive heat. Because, as then advised, he saw no other way of accounting for its being now-a-days in a melted state. He has recently abandoned that idea, because he now sees no other way of accounting for matter being at present in a melted state, except by modern oxy-hydrogen flames. The disposal of their meltings *must* be accounted for. And therefore he now affirms, the issues of melted lava of to-day are due to newly melted solids, operated on by hydrogen burning in oxygen.

Secular Refrigeration.

The annual creation of new heat, by reason of hydrogen and oxygen burning together, must be so

very great, that it will be difficult to prove the existence of *any* secular refrigeration—namely, to prove that, on balance, the earth now loses *any* heat.

Water gets down to volcanic and earthquake foci in various ways.

Sea-water gets down to the burning gases, because sea-salt comes out at the top of Vesuvius, and because on one occasion the water in the Bay of Naples sunk two Naples palms of 10·38 English inches each, total 20·76 English inches. And the whole rise of tide in the bay being only about two English feet, in calm weather, two palms would be a very perceptible quantity.

In a paper read by M. Pissis before the French Academy, see 'Comptes Rendus,' Jan. 27, 1862, he says, "It is generally believed, in the districts of South America which are most subject to earthquakes, that those disturbances occur during the rainy season, and up to the period of drought." During 12 years of his own residence on the spot this theory held good; and the years of most violent rain were distinguished by a great number of earthquakes.

Mr. Dana and Dr. Junghuhn say that the volcanoes of the Pacific Islands, however large, however much exposed to heavy rains, support no rivers, so long as they are in process of growth, or whilst the highest crater emits showers of scoriæ, and floods of lava. The ejected matters are very porous.—Lyell's *Manual*, 1855, p. 497.

The like is true of Etna, for we read as follows :—

"An unusual silence prevails on the Val del Bove, Etna; for there are not torrents dashing from the rocks, nor any movement of running water in this valley, such as may be almost invariably heard in mountainous regions. Every drop of water that falls from the heavens, or from the melting ice or snow, is instantly absorbed by the porous lava."—*Principles of Geology*, 1853, p. 405.

It is well known that on the shores of the Isle of Cephalonia there is a cavity in the rock into which the sea has been flowing for ages, and many others doubtless exist in the leaky bottom of the ocean. The water perhaps being converted into steam and escaping upwards.—*Ibid.* p. 389.

To send powerful electric shocks one-fourth round the globe in very brief spaces of time, is exactly what Nature can do, and does with the greatest facility.

Disbelief in the enormous power of saturated steam.

There is a tendency abroad amongst a few, to disbelieve the accounts, even when well authenticated (of some of the grandest effects of volcanoes and earthquakes; such as, that great blocks of basalt were thrown to the distance of 7 miles from Galangung in 1822. This is very unphilosophical. The grand temperature of hydrogen burning in oxygen (8061° Centigrade [equivalent to 14,541° Fahrenheit]) may be relied on; Professor Tyndall is a safe man to follow. We are bound to

account for the disposal of, and to employ, this very high temperature. We have endeavoured to do so in a satisfactory manner. Table I. of the sequel is so near absolute correctness, that its results never differ as much as a unit per cent. from the averages of a very large series of first-class experiments. And in 48 cases out of 52 they differ less than half a unit per cent. from calculations by the formula. In the 18 cases of Table II. (after applying the small modification described) they seldom differ more than half a unit per cent. from the averages of a copious series of first-class experiments. The modification in Table III. becomes only 1 in 4722 for 932 tons. And for the *maximum* force, the modification reduces itself to a single unit in about 1 million. Thus practically the net formula is pure and simple, viz., that the pressure of steam above 285° Fahrenheit increases as the 4·5 power of the temperature. Not one of the facts, we believe, stated in the whole of this tract is inconsistent with the proposition that saturated steam is the sole motive power in volcanoes and earthquakes.

Strength of Great Guns.—The strongest metal known to civilisation is cast steel, which Weale's 'Engineer's Pocket-book' gives at 134,256 lb. [59·93 tons] per square inch. Suppose the reinforce of a gun formed of this material, and a yard thick, we should have for its ultimate strength or bursting force 59·93 × 36 or 2157·48 tons per square inch. But the gun ought not to be subjected to an explosive force of more than one-eighth of this, or not quite 270 tons per square inch. Beardmore's

'Manual of Hydrology,' p. 71, gives the strongest metal, soft steel, 120,000 lb. per square inch.—How infinitely below the grandeur of volcanoes and earthquakes all this is!

We have known a reviewer to pick out an individual paragraph in a publication, and endeavour to turn that into ridicule, wholly passing over unnoticed the remaining 99 parts of the publication. We can do nothing for those (if any) who cannot believe, after fairly considering the whole of the many demonstrations contained in this tract, which all point in one and the same direction, viz. that saturated steam is the motive power.

Any courteous communication on the subject of this tract will receive the author's best attention and an answer if required.—41, Osborne Road, Tollington Park, London, N. *April*, 1882.

SECTION XIX.

Reprint of parts of Tract of June 1866, with additions—Melting, boiling, and fire heats, Professor Daniell—Various substances melt at temperatures named—Supposed heat of subterranean fusion—Extracts from an unpublished MS.—M. Regnault's admirable experiments on steam pressures and temperatures—Gay Lussac—Humboldt—Ejections of steam or aqueous vapours from volcanoes—Earthquakes are actually fed by water—Active volcanoes are actually fed by water—Rocks ejected from a volcano by steam—Deposits of water, and of ice and snow, ready to descend into volcanoes by gravitation through the porous strata—Ejections of steam from geysers—Active volcanoes beneath the

sea must necessarily produce both steam and earthquakes—Submarine eruptions in very deep water—Submarine eruptions at less depth—Ejections of steam from earthquakes—Ejections of water and of mud (which implies the presence of water) from volcanoes, also sinkings of rivers and other waters—Ejections of water, often hot, from earthquakes and from risings and sinkings of strata, and from earthquakes combined with volcanoes—Volcanoes, earthquakes, hot water and increasing temperature of hot springs, sometimes all connected together—Expected eruption of Vesuvius.

Following is a reprint, with additions, of certain parts of a tract, first published by the present writer in June 1866, and entitled 'Steam, Volcanoes, and Earthquakes.'

The following evidences prove the very frequent presence of *water*, the parent of steam, in some of its forms, in volcanoes and earthquakes, &c.

(1) Bismuth melts, 471-6°.—*Dixon on Heat.*
(2) Lead melts, 576°.
(3) Iron, red heat in the dark, 635°.
(4) Linseed oil boils, 640°.
(5) Mercury boils, 662°.
(6) Charcoal burns, 802°.
(7) Antimony melts, 810°.
(8) Iron dull red heat, 980°.
(9) Heat of a common fire, 1141°.

The following are the several melting heats of some of the more refractory metals, with the hypothetical pressures of steam of equal temperatures calculated by the formula:

Calculations of Pressure in Tons per sq. in.			
114	..	Brass melts at	1869° (11) Fahr.
115	..	Silver „	1873° (12) „
153	..	Copper „	1996° (13) „
237	..	Gold „	2200° (14) „
326	..	.. ..	2360° (15) „
687	..	Cast iron melts at	2786° (16) „
959	..	Subterranean fusion	3000° (17) „

The temperatures marked [6],[8],[9],[11],[12],[13],[14],[16], are on the authority of Professor Daniell, F.R.S. The temperature 2360 is stated by Dr. Macquorn Rankine, F.R.S., to be that at about which the water in an engine boiler would be totally evaporated. (*Artizan*, Nov. 1863, p. 252.) In Sir W. G. Armstrong's address to the British Association at Newcastle (p. 9.), he assumes the temperature of subterranean fusion to be 3000° Fahr. The other melting points, &c., have been obtained from a small volume on steam, published by the late Mr. Weale.

Extracts from an unpublished MS.

But it was right to go to the fountain head, and accordingly vol. xxi. of 'Mémoires de l'Institut' has been referred to, where M. Regnault gives a full account of his steam experiments for the French Government, and many tables of results. His experiments are as nearly perfect as anything merely human could be expected to be. In fact, more nearly so than could *a priori* have been expected, when we consider the many difficulties and dangers which he had to encounter and overcome. He gives the pressure in millimètres of mercury, taking 760 millimètres to an atmosphere. And he takes as his standard the Observatory of Paris in latitude 48° 50′ at 60 mètres (196 ft. 10 in.) above the level of the sea. Sir John Herschel gives* "mean

* 'Outlines of Astronomy,' 1864, p. 716.

barometric pressure at sea level on 1 square inch in pounds, 14·7304." But the pressure would be less than that at the Paris Observatory, nearly 200 ft. above the sea.

Specific gravity of mercury at 32° Fahr. (water at 40°)*	13·596
Hence a cubic foot of mercury weighs lb. ..	849·75
And a column of mercury a mètre high (39·37079 English inches)* and one inch square, weighs lb.	19·360678
And an atmosphere of 760 millimètres therefore weighs lb.	14·714132
And it follows that an atmosphere will be equal to a column of mercury of the height, inches	29·9218

At pp. 625–6 M. Regnault gives a table "des forces élastiques de la vapeur aqueüse," from which may be gathered, by comparison with his table at p. 608, that the latter was calculated by his formula H. Table II., now given, is calculated from data obtained from his table at pp. 625–6, and it will be seen that his formula gives results all but identical with the $4\frac{1}{2}$ roots of the pressures, the differences being quite insignificant, for they range only from $+\frac{1}{48}$ to $-\frac{1}{8703}$. There is therefore practically no difference between his formula and that used by the present writer.

Gay Lussac says that "the penetration of sea water does not appear to him to be improbable under certain conditions."—Foot-note to Bohn's *Cosmos*, vol. v. p. 169.

It is well known that the late Baron Humboldt

* 'Outlines of Astronomy,' 1864, p. 716.

examined more volcanoes than perhaps any other man ever did, and that he experienced some earthquakes in South America and in the East. His "difficulty" aforesaid, besides being answered by himself in the same sentence, is also answered by him in No 69 following, by what he aptly calls "a very striking proof" of water having got down to a volcanic focus. Water must get down to a volcanic focus, because we shall often find steam and hot water coming out again.

Ejections of Steam or Aqueous Vapour from Volcanoes.

1. Sir Humphry Davy says, the volcanoes of Central America give out aqueous vapour in very large quantity, as well as certain gases.—Lyell's *Principles of Geology*, 1853, p. 549.

2. In the explosion of the volcanic mountain Conseguina in Central America, there was a noise as of many cannon from various parts of the Gulf of Fonseca. An enormous coal-black cloud of smoke rolled high above the summit of the volcano. This cloud was fine ashes so abundant as to produce darkness. There was a tremendous subterranean report as of a thousand cannon, heard at several hundred miles distance.* The eruption was most violent for three days. Clouds of steam continued to rise from the volcano for months

* Humboldt says at nearly 560 geographical miles distance.—Bohn's *Cosmos*, vol. v. p. 275.

after. The eruption commenced January 20, 1835.—*Travels in the Free States of Central America*, by Dr. Carl Scherzer, vol. ii. p. 224, &c.

This account is to a great extent confirmed by Stephens and Catherwood, p. 247.—*Incidents of Travel in Central America*, 1854.

2*a*. *Travels in the Free States of Central America.* By Dr. Carl Scherzer, vol. ii. p. 227. Longmans, 1857.

"The regularity of the intervals between the detonations, and their continual repetition, soon made it evident that the thunder did not proceed from the electrical discharges of clouds in a high region of the atmosphere, but from below, in the bowels of the earth. The darkness extended far inland in the State of San Salvador; but in the town of San Vicente, in the centre of the Republic, it was no longer so dense."

The four following evidences are from Sir Charles Lyell:—

3. At the great eruption of Skaptàr Jokul in 1783, in some places where the steam could not get vent, it blew up the rock, throwing fragments to the height of more than 150 feet. About a month previous to the eruption on the main land, a submarine volcano burst forth in the sea, and a new island was thrown up (which volcano must necessarily have produced steam); the island was named, by the King of Denmark, Nyöe, or the New Island, consisting of high cliffs; but before the end of a year nothing was left but a reef of rocks

from 5 fathoms to 30 fathoms under water. (This is similar to what took place at Graham Island, see *post*, No. 51.) Earthquakes, which had long been felt in Iceland, became violent on the 11th of June, 1783, when Skaptàr Jokul on the mainland, distant nearly two hundred miles from Nyöe, threw out a torrent of lava.—*Principles*, p. 425.

Besides proving the existence of steam, this proves two other things, namely—that the same causes operate both in earthquakes and volcanoes; and secondly, that there may be cavities, or at all events, fissures or communications, continued through the great distance of two hundred miles. The like may be gathered as to distant communications underground from Nos. 24 and 59.

4. "Aqueous vapour constitutes the most abundant of the aëriform products of volcanoes in eruption."—*Principles*, p. 553.

5. "We know that volcanoes in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years, continuously, and are even disengaged from lava during its consolidation."— Lyell's *Manual*, p. 601. (Ed. 1855.)

6. Sir Charles quotes Sir H. Davy as stating that the subterranean cavities of Vesuvius threw out large volumes of steam during an eruption.—*Principles*, p. 550.

7. Schmidt saw clouds of volcanic smoke and steam, which encompassed his observatory on Vesuvius during the great eruption of 1855.—*Intellectual Observer*, vol. i. p. 149.

8. Whoever has seen the blowing off of steam from a boiler will probably recognise Sir William Hamilton's "mass of smoke like whitest cotton," in the following abstract, as steam. This opinion is corroborated by the latter part of No. 51, following.

Sir William says that for two years previous to the eruption of Vesuvius in 1779, its top had never been free from smoke. On August 5th he saw a mass of smoke like whitest cotton issue, four times as large as the mountain itself, which is 3700 feet high; stones, scoriæ, and ashes shot up at the same time 2000 feet; at times heavy liquid lava poured forth over the sides of the crater. On August 8th there was a loud report, and instantly a column of liquid transparent fire rose as high as the mountain itself; puffs of very black smoke accompanied, and at the same moment could be seen bright electrical fire playing briskly in zig-zag lines.

Sir William mentions this circumstance to prove "that the electrical matter so manifest during this eruption, actually proceeded from the bowels of the volcano, and was not attracted from a great height in the air and conducted into its crater by the vast column of smoke."—*Phil. Trans. R.S.*, 1780, vol. xiv. p. 616.

On August 9th there was a subterraneous boiling noise, and smoke of two sorts, white as snow and black as jet, the black being scoriæ and minute ashes. Very large stones mounted to an immense height, forming parabolas, leaving a trace of white smoke. Some burst like bombs, others burst into a thousand pieces soon after emission. On August 11th the last explosion came, and gradually increased, being louder than any before. A mountain of white cotton-like clouds rose to an extraordinary height, and formed a colossal mass. indescribably great.—*Phil. Trans. R.S.*, 1780, vol. xiv. p. 616, &c.

May we not conclude that on this last day Vesuvius was blowing off its steam, its business being finished for the time? Sir William made his observations from Pausilippo through a good telescope. He was not on the spot so as to ascertain whether the "white smoke" was steam or not.

8*a*. In Professor Palmieri's 'Vesuvius,' translated by Mr. Mallet, p. 97, it is stated:—

"Not only the Vesuvian cone, but the whole adjacent country, appeared white for many days, as if covered with snow, when exposed to sunlight. This was due to the sea-salt contained in the ashes with which the surface was strewn."

9. Mr. William Smith, C.E., F.G.S., proprietor of the *Artizan*, has lately visited Vesuvius and Etna, and says, in answer to a question, in a letter dated June 23, 1865,

"he thinks steam is generated during volcanic action, and is a material agent in the production of those explosive effects which are observable both at Etna and Vesuvius."

10. Mr. J. J. Jeans, British Vice-Consul at Catania, says, in a letter dated Feb. 4, 1865: "A deplorable accident has happened at Etna by an explosion caused by the contact of burning lava with some cistern or watercourse; by the effects of which a number of sappers have lost their lives, but the particulars are not known."—*Illustrated London News*, Feb. 25, 1865.

Here we have a distinct proof of lava converting water into steam, and causing a destructive explosion. The following analysis of the constituent parts of lava is interesting. It is an extract from the *Express*, quoted in the *Record* newspaper of October 19, 1868.

Constituents of Lava.

What is Lava?—A telegram states that "the eruption of Mount Vesuvius is increasing in intensity, the flow of lava is more copious, and the dynamic action of the cone more vigorous." But what is lava? Coming no one knows whence, it might be suspected to be formed of, or at least to contain, unusual substances; but such apparently is not the case. Here is an analysis, by M. Silvestri, of lava recently thrown out of

Vesuvius:—Silica, 39; lime, 18; alumina, 14; magnesia, 3; protoxide of iron, 13; potash, 1; soda, 10; water, 2; which means that the specimen closely resembled common wine-bottle glass. In short, lava, though varying considerably in colour and solidity or friability, and occasionally containing little groups of crystalline minerals, would seem to be a sort of rough natural glass or earthenware, mainly produced from sand, chalk, clay, and similar common earthy substances.—*Express.*

11. M. Fouqué has communicated to the Academy of Sciences an account of his recent ascent of Mount Etna. He states that the eruption of February 1865 has not materially changed the configuration of the great crater . . . . It is only towards the south that he found fissures from which were issuing torrents of suffocating fumes, composed of steam charged with sulphuric and hydrochloric acid, the latter predominating. He found a "fumarole" with a temperature of 203° Centigrade, which is equal to 397·4° Fahrenheit.

12. From *Art and Nature under an Italian Sky*, 1850, p. 110, published anonymously, we gather that just as the author reached the base of the cone of Vesuvius a magnificent explosion took place. The sound has often been compared to the firing of artillery, but he thought a much more apt comparison was the bursting of an immense steam boiler. A vast quantity of red-hot stones was projected, some of them to the

height of 300 feet. The projecting force is evidently steam, he says, from the appearance of the vapour and the shower of hot water which falls around.

13. In a recent eruption of Mount Vesuvius, aqueous vapour and storms of ashes issued. At Torre del Greco a sea whirlpool of 360 feet diameter was boiling violently and emitted a strong sulphurous odour: the sounding was 23 fathoms. The principal development was carbonic acid gas.—*Morning Advertiser*, Dec. 28, 1861.

Was the water descending by the whirlpool to the volcanic focus?

14. Von Buch found that in a crater in the Canary Islands were open fissures out of which hot vapours rose, which in 1815 were 145° Fahr., and were probably at boiling point lower down. The exhalations appeared to be aqueous vapour, but they could not be pure steam, for the crevices were incrusted with siliceous sinter.—*Principles*, p. 438.

15. From near the centre of the volcanic mountain Bromo in Java (see 'Voyage of H.M.S. *Fly*,' vol. ii. p. 68), rises a rough conical mound, 600 or 800 feet high, having on one side a number of subordinate craters. One of these had been frequently active in 1845 when Mr. Jukes visited it, and was then belching out much smoke and steam, with a great rumbling noise proceeding from the depths of the funnel-like crater.—Jukes's *Manual of Geology*, 1857, p. 291.

16. James D. Dana, the geologist of the United States

exploring expedition, says, in his vol. x. p. 368, " That the ordinary eruption and usual action of a volcano proceed principally from water gaining access to a branch or branchlets belonging to a particular vent, and not to a common channel below: the fresh waters of the island are the principal source of the vapour [evidently steam*] of Kilauea." This is one of several deliberate conclusions which Mr. Dana arrived at.

17. Mr. Coan was present, in December 1864, at the eruption of the volcano of Kilauea in one of the Sandwich Islands. He spent a night near a beautiful pit crater called Napau, nearly circular, about 300 feet deep, a mile perhaps in diameter, and with a bottom of sand so smooth and hard that a regiment of cavalry might be reviewed there. One-eighth of a mile from this crater fissures are opened in the earth, out of which scalding steam and smoke have issued from time immemorial, and affording heat enough to cook for an army.—*American Journal of Science*, quoted in *Illustrated London News*, Oct. 28, 1865, p. 415.

18. The island of Hawaii, formerly called Owhyhee, is an immense volcano of 4000 square miles, its summit Mowna Loa being 16,000 feet high; volumes of smoke and steam were ascending from the vents, but as the evening closed, fire after fire appeared glimmering through the vapour: some of the cones were ejecting fragments of rock; others ashes, lava, and

* The words "evidently steam" have been inserted by the present writer, not by Mr. Dana.

boiling water.—*Gallery of Nature*, p. 210; Mantell's *Wonders of Geology*, p. 724, &c.

18*a*. According to letters recently received from Honolulu, it appears that the late volcanic disturbances in that island have been of extraordinary intensity. In the district of Kaui all the native villages along the seashore for a distance of 20 miles have been destroyed by tidal waves and by the upheaval of molten lava. Houses were in a state of nearly constant vibration for six hours. Avalanches of earth were cast into the sea, and walls and houses thrown down. The entire island seemed like a great ship loosened from her moorings, reeling to and fro, rising and falling, shaking terrifically as if it were going to pieces. Every one wanted something to hold on by, but there was nothing firm. At length, after 11 days of intense anxiety and suffering, during which upwards of 200 persons lost their lives, comparative quiet was restored to the island, by the opening on the 7th of April of a new and vast crater on the S.E. side of Mowna Loa, which gave vent to the pent up lava and gases.—*Athenæum*, July 1868, p. 22.

19. "Chimborazo throws out masses of mud and elastic fluids."—*Cosmos*, vol. v. p. 336.

Note.—Mud implies the presence of water.

19*a*. Mr. J. M. Hutchings in *Scenes of Wonder and Curiosity in California*, p. 177, in describing the top of Mount Shasta, 17,000 feet high, says:—"I was evidently upon the original and main crater. . . . A

hundred little boiling springs were gurgling and bubbling up through a bed of sulphur, and emitting steam. . . ."

Earthquakes are actually fed by Water.

20. In a paper read by M. Pissis before the French Academy, see 'Comptes Rendus,' Jan. 27, 1862, he says, "It is generally believed in the districts of South America which are most subject to earthquakes, that those disturbances occur during the rainy season, and up to the period of drought." During twelve years of his own residence on the spot this theory held good; and the years of most violent rain were distinguished by a great number of earthquakes.

Active Volcanoes are actually fed by Water.

21. Mr. Dana and Dr. Junghuhn say that the volcanoes of the Pacific Islands, however large, however much exposed to heavy rains, support no rivers, so long as they are in the process of growth, or whilst the highest crater emits showers of scoriæ and floods of lava. The ejected matters are very porous.—Lyell's *Manual*, 1855, p. 497.

22. The like is true of Etna, for we read as follows:— "An unusual silence prevails on the Val del Bove, Etna; for there are no torrents dashing from the rocks, nor any movement of running water in this valley such

as may be almost invariably heard in mountainous regions. Every drop of water that falls from the heavens, or from the melting ice or snow, is instantly absorbed by the porous lava."—*Principles*, p. 405.

"Running water in general exerts no power on Etna the rain which falls being immediately imbibed by the porous lava, so that, vast as is the extent of the mountain, it feeds only a few small rivulets, and even these are dry during the greater portion of the year." —*Principles*, p. 411.

23. It often happens that a lake which has endured for centuries in a volcanic crater, disappears suddenly on the approach of a new eruption.—*Principles*, p. 389.

24. It is well known that on the shores of the island of Cephalonia there is a cavity in the rock into which the sea has been flowing for ages, and many others doubtless exist in the leaky bottom of the ocean; the water, perhaps, being converted into steam and escaping upwards.—*Principles*, p. 389.

In the *Record* newspaper of February 20, 1867, there are some extracts from a letter signed "A Traveller," and dated Corfu, February 14, and referring to the earthquake in Cephalonia of February 4. "Every day and every night since the great catastrophe of the 4th inst., there had been a succession of smaller shocks.

"On the night of the 11th inst. these shocks were especially frequent, and on the morning of the 12th, from 1.30 A.M. to 3 A.M., I counted no less than eight shocks, three of them being severe, especially one at

3 A.M., which caused an already shattered house to fall. . . . At Argostoli (in Cephalonia), some of the piers of Sir C. Napier's causeway have sunk several feet; part of the quay too has fallen below its former level. . . . About a mile and a half north of Argostoli currents of water rush into the land from the sea, turning two under-shot flour mills, and then disappearing into caverns in the earth. Some years ago, boats having been stationed round the island, a quantity of oil and feathers was floated down these streams, but neither feathers nor oil were seen to reappear, and the cause of the phenomenon remained unknown. I inquired at one of the mills whether, since the earthquake of the 4th inst., any change had been observed in these streams. The answer was in the negative, but I was informed that it was in this district that the shock seemed to be first felt. . . . It is generally thought that there is a volcano beneath the island."—It would be a valuable experiment, on the score both of philosophy and humanity (as the loss of life and property was great) to compensate the mill-owners and dam up and stop the inrush of the waters.

Note.—Cephalonia is 300 miles distant in a direct line from Etna, and from the stufas of the Lipari Isles, and 360 miles from Vesuvius, which appear to be the nearest vents. There may, therefore, be a cavity or cavities extending for either of these distances.

Rocks ejected from a Volcano by Steam.

25. Speaking of the angular masses of the agglomerate of the Caldera of Palma, Sir Charles Lyell says that "the only cause he knows capable of dispersing heavy fragments of 3 feet, 4 feet, or 6 feet in diameter, without blunting their edges, is the power of steam; unless, indeed, we could suppose that ice had co-operated with water in motion; and the interference of ice cannot be suspected in this latitude (28° 40′ N.), especially as he looked in vain for signs of glacial action here and in the other mountainous regions of the Canary Islands."—*Manual*, 1855, p. 503.

Deposits of Water, and of Ice and Snow, ready to descend into Volcanoes by Gravitation through the Porous Strata.

26. "At Volcan d'Ansango are two chasms filled with water."—*Cosmos*, vol v. p. 336.

27. There are several marshes and two small lakes in the long and broad ridge which unites the volcanic mountains Cotopaxi and the Nevado de Quelandana.—*Cosmos*, vol. v. p. 339.

28. In the crater of the volcano of the Island of S. Lucia are several small basins periodically filled with boiling water.—*Cosmos*, vol. v. p. 422.

29. The thirty-eight considerable volcanoes of the

Isle of Java are remarkable for the quantity of sulphur and sulphurous vapours discharged. They rarely emit lava, but rivers of mud issue from them. The crater of Taschem contains a lake a quarter of a mile long strongly impregnated with sulphuric acid.—*Principles*, p. 353.

30. The Persian volcano, Demavend, is covered with perpetual snow.—*Cosmos*, vol. v. p. 361.

31. Two volcanic mountains, Petschan and Hotshen, of Turfan (Asia), are separated by a gigantic block of mountains 420 miles long, crowned with eternal snow and ice.—*Cosmos*, vol. v. p. 360.

32. The most extensive and, probably, the latest pre-historical eruptions of Ararat, have all issued below the limit of perpetual snow.—*Cosmos*, vol. v. p. 361.

It is obvious that in the many other cases where volcanoes have their tops higher than the limit of perpetual snow, there is a means of producing steam ready to descend. And it ought not to be forgotten that nearly all the volcanoes in the world are either in the bed of the Pacific Ocean or in its islands, or not far distant from its shores; and they are doubtless fed by its waters directly, or by its rains indirectly.

Ejections of Steam from Geysers.

33. "Steam is exclusively the moving power in the geysers of Iceland."—Lyell's *Principles of Geology*, p. 553.

34. "It has more than once happened after earthquakes (in Iceland) that some of the boiling fountains have increased or diminished in violence or volume, or entirely ceased, or that new ones have made their appearance."—*Ibid.*

Note.—Does not this prove the connection of geysers and earthquakes?

35. "Steam of high temperature has continued for more than twenty centuries to issue from the 'stufas' of Italy," and "many craters emit hot vapours in the intervals between eruptions, and solfataras evolve incessantly the same gases as volcanoes," proving them to have one common origin.—*Ibid.*, p. 549.

36. At the foot of Sulphur Mountain, in Iceland, steam issued from all parts. There was a caldron of boiling mud fifteen feet in diameter; near this was an irregular space filled with water boiling briskly, and at the foot of the hill steam rushed with great force from among the loose fragments of rocks.—Sir George Mackenzie's *Travels in Iceland.*

37. Such is the explosive force of steam of the Great Geyser of Iceland, that very hard rocks are sometimes shivered by it into very small pieces.—*Principles*, p. 554.

38. At the geysers near San Francisco Bay, California, the air is strongly flavoured with sulphur, and the water is strongly ferruginous. There is an alkaline spring surrounded with jets of sulphur, and deposits of magnesia, Epsom salts, and various alkaline mixtures. You hear boiling springs, and are half choked with

steam. A horrible mouth in the black rock belches forth tremendous volumes of sulphurous vapour. The waters boil in mad fury, the temperature is about 500°. An egg dipped in is taken out boiled. The steam rushes from the largest vent hole with such force, and heated to such a degree, that it first becomes visible only at the distance of 6 feet from the earth. It rises to the height of 80 feet.—*Home and Abroad*, second series, by Bayard Taylor, p. 81, &c.

39. It is said of a mud volcano, about 150 miles from the head of the Gulf of California, that those only who are familiar with the wild rush of steam can realise the rude sounds of the mud explosions. The steam jets issue from conical mounds of mud of from 3 to 15 feet high: from some the steam rushes in a continuous stream; in others, the action is intermittent, each rush of steam being accompanied by a shower of hot mud, sometimes thrown to a height of 100 feet. These discharges take place every few minutes. The volcanic action has been more violent at a former period, as is proved by the traces of former eruptions, and fragments of pumice stone scattered about the plain.—John A. Veatch, M.D., *Titan*, April, 1859, p. 465, &c.

I endeavoured, in citing these evidences, to classify volcanoes, earthquakes, geysers, hot springs, &c., each under different headings. But they would commingle with each other, especially in what follows; and they thereby prove that they have all one common origin, namely, steam.

Active Volcanoes beneath the Sea must necessarily produce both Steam and Earthquakes.

40. The Gulf of Santorin, in the Grecian Archipelago, has been for 2000 years a scene of active volcanic operations. The gulf contains three volcanic islands, namely, Old, New, and Little Kaimeni. Pliny informs us that Old Kaimeni rose above the water in B.C. 186. It was increased in size by other eruptions in A.D. 19, 726, and 1427. In 1572 another eruption produced Little Kaimeni. In 1650 a submarine outbreak gave rise to a shoal, which was surveyed in 1848 by Captain Graves, and found to have 10 fathoms of water over it, the sea deepening around it in all directions. This eruption lasted three months, covering the sea with floating pumice. At the same time an earthquake destroyed many houses in Thera.—*Principles*, p. 441.

It is well known that Santorin has been for some time and is now in active operation, sending forth clouds of steam and flames, and giving earthquake shocks.

Submarine Eruptions in very deep Water.

41. "In the 'Nautical Magazine' [says Sir Charles Lyell] for 1835, p. 642, and for 1838, p. 361, and in the 'Comptes Rendus,' April 1838, accounts are given of a series of volcanic phenomena, earthquakes, troubled

water, floating scoriæ, and columns of smoke, which have been observed at intervals since the middle of last century, in a space of open sea between longitudes 20° and 22° west, and about ½° south of the equator." —*Principles*, p. 436.

42. "Submarine volcanic action near the equator has been for some years going on. We have now two accounts of it observed by ships but a few miles apart from each other—the *Dallas*, Captain Wikander, and the *Melbourne*, Captain Cowie—on March 20, 1861. The latter says:—'We were startled by a heavy and loud rumbling noise, and at the same time felt the ship tremble from stem to stern, which lasted four or five minutes. The noise resembled more the low grumble of distant thunder than the harsh, grating noise produced by the ship's taking ground. The *Dallas* lost her false keel by the collision.'"—*Illustrated London News*, Aug. 17, 1861, p. 157.

42*a*. "A fearful storm and submarine earthquake is reported to have occurred in the Atlantic at midnight on the 8th and 9th of November. It is stated that large meteors shot from the heavens, and the fish jumped out of the sea and struck against the sides of the ship, which trembled so that the rumbling could be distinctly felt as well as heard."—*Record*, Dec. 9, 1868.

43. "Feb. 9, 1835, at 10 hours 45 minutes, on board the barque *La Couronne*, of Liverpool, a shock was felt at sea in 0° 57′ south latitude, and 23° 19′ west of Greenwich." See 'Comptes Rendus,' t. vi. p. 514,

as quoted by Lieut. Maury in *Physical Geography of the Sea.*

Note.—From Lieut. Maury's chart the sounding would be about 3000 fathoms, and the inertia of the water 8031 lb., or more than 3½ tons, per square inch.*

44. *A Volcano in the Ocean.*—The ship *Orient,* 1032 tons, Captain John Harris, the arrival of which with a cargo of wool, &c., has already been announced, and which sailed from Adelaide Nov. 10, brings the report that on Friday, Nov. 17, at 7.15 A.M., when in latitude 51° 44′ S. and longitude 160° 49′ W.,† with a moderate wind from N.N.W., and a clear sky, the ship commenced ringing the bells and trembling violently, as if she were passing over a rough bottom in shallow water. In an instant all was confusion on board, as the crew and passengers thought she was settling down. The violent trembling lasted two or three minutes, with nothing visible. Sounded the pump well and found no water; and sounded over the ship's side with the deep sea lead, but found no bottom. The conclusion arrived at by all on board was, that the ship had experienced the effects of a submarine volcano.—*Morning Advertiser,* Feb. 16, 1866.

* Lieut. Maury did not know of the lofty ridge which runs all along the Atlantic from north to south. The point in question is on this ridge, and the sounding and pressure are only about half as great as here stated. The subject will be again referred to in the sequel.

† Some 1400 miles east from the nearest land, which is the south island of New Zealand.

Submarine Eruptions at less Depth.

45. *An Earthquake at Sea.*—Captain P. E. Lawson, of the barque *Viking*, of Sunderland, reports that on the 16th ult., at 2 P.M., while in latitude 36° 18′ north, and longitude 2° 32′ west (which position is in the Mediterranean, 165 nautical miles east of Gibraltar, opposite the Bay of Almeria), he experienced a severe shock of an earthquake, as though the ship had taken a shoal of rocks; and so severe was it that the vessel was shaken with great violence, and everything on board was similarly affected. This lasted about five minutes, when the shock subsided, and the vessel resumed her course, nothing the worse for the severe shaking she had undergone. The weather at the time was beautifully fine, and the water remarkably clear.—*Record* Newspaper, Aug. 21, 1865.

46. "On the 20th Nov., 1720, a burning island was raised out of the sea near Tercera, one of the Azores, at which place several houses were shaken down by an earthquake which attended the eruption. This island was about three leagues in diameter and nearly round; whence it is manifest that the quantity of pumice stones and melted matter requisite to form it must have been amazingly great."—Rev. John Michell, *Phil. Trans. R.S.*, 1760, p. 452.

47. Another example of the same kind happened at Manilla in 1750. This, also, was attended with violent earthquakes, to which that island, as well as the rest of *the Philippines*, is very much subject.—*Ibid.*

48. Barren Island in the Bay of Bengal, east of the Andaman Isles, in latitude 14° 15′ N., when seen from the ocean, presents on almost all sides a surface of bare rocks rising with a moderate acclivity towards the interior; but at one point there is a cleft by which we can penetrate into the centre, and there discover that it is occupied by a great circular basin filled with the waters of the sea, and bordered all round by steep rocks, in the midst of which rises a volcanic cone very frequently in eruption.—*Principles*, p. 466.

49. In 1835, a submarine volcano broke out near Bacalao Head, Isle of Juan Fernandez, about a mile from the shore, in sixty-nine fathoms of water, and illuminated the whole island during the night.—*Principles*, p. 454.

50. In the Aleutian Archipelago eruptions are frequent, and about thirty miles north of Unalaska, near the Isle of Umnack, a new island was formed in 1796. It was first observed at a point in the sea from which smoke had risen. Flames then issued from the new island which illuminated the country for ten miles round; a fearful earthquake shook the new-formed cone, and showers of stones were thrown as far as Umnack.—*Principles*, p. 352.

Note.—The flames in the water in the two last evidences cannot have failed to produce steam.

In 1806 another and in 1814 a third submarine island arose among the Aleutian Islands.—*Principles*, p. 468.

Note.—There are vast tracts of submarine volcanoes. See Lyell's *Principles of Geology*, p. 350, &c.

51. Graham Island, off the south-west coast of Sicily, thirty miles, rose in July 1821, in 100 fathoms water, steam playing an important part, and disappeared again in three months. The following are a few details:—

About a fortnight after the eruption was first visible, Sir Pulteney Malcolm passed over the spot in his ship and felt the shock of an earthquake, and the same shocks were felt on the west coast of Sicily—direction S.W. to N.E About July 10, John Corrao passed in his ship near the place, and saw a column of water 60 feet high and 800 yards in circumference, rising from the sea, and soon after a dense steam in its place rose to the height of 1800 feet. On his return from Girgenti on July 18, he found a small island 12 feet high with a crater in its centre, ejecting volcanic matter and immense columns of vapour. In August, there was a violent ebullition and agitation of the sea on the south-west side of the island, indicating a second vent not far from the surface.—*Principles*, pp. 432, 434.

There is a similar account in Milner's 'Gallery of Nature,' p. 376, &c., which says, in addition, that Admiral Sir H. Hotham sent an officer to report, whose account confirms the preceding statement. This officer particularly mentions the vast volumes of pure white steam, which tends to corroborate the opinion expressed in No. 8, that Sir William Hamilton's white cotton-like vapour was steam. We have had, and shall have, abundance of proofs that Vesuvius ejects vasts quantities of steam and boiling water.

Ejections of Steam from Earthquakes.

Are not the two following cases proofs that steam must be the cause of earthquakes?

52. At Deception Island, Tierra del Fuego, where earthquake shocks are of most constant occurrence, there are no less than 150 chasms or fissures, from which steam pours forth with a loud hissing noise.—*Chambers' Edinburgh Journal*, Aug. 17, 1861, p. 157.

53. Baron Humboldt says that hot steam was ejected during an earthquake in 1812, at New Madrid, in the valley of the Mississippi.—*Cosmos*, vol. i. p. 209.

Ejections of Water and of Mud (which implies the Presence of Water) from Volcanoes, also Sinkings of Rivers and other Waters.

Following are some additional evidences that steam issues from Vesuvius, and necessarily in vast quantities, for it becomes condensed into torrents of water, which descend the cone, and are as destructive as lava itself. Lava is generally ejected from volcanoes during eruptions, but is not always mentioned in these evidences, because the object now is to exhibit aqueous products, not molten matter.

54. "Not long before the eruption of Vesuvius in 1631, in one part of the plain (at the foot of the cone) covered with ashes, were three small pools, one filled with hot and bitter water, another salter than the sea,

and a third hot and tasteless. In December 1631, great floods of mud were as destructive as the lava itself; no uncommon occurrence during these catastrophes; for such is the violence of rains produced by the evolutions of aqueous vapour, that torrents of water descend the cone, and become charged with impalpable volcanic dust, and rolling along loose ashes, acquire sufficient consistency to deserve their ordinary appellation of aqueous lavas."— *Principles*, p. 374.

55. From *Gallery of Nature*, p. 781, we learn that:— "Among the peculiarities of Vesuvius the emission of boiling water from its flanks has often been remarked; this is not uncommon with Transatlantic volcanoes, together with torrents of mud—a compost of water and ashes—forming a fetid clay."

56. It is stated in the Encyclop. Brit., vol. xvii., in an article attributed to Sir John Herschel, Bart., F.R.S., that "an earthquake happened in 1631 at Mount Vesuvius, which covered with lava most of the villages at its foot, and sent forth torrents of boiling water."

57. The following is so important and so full of significant facts, that it is quoted almost entire from *Principles*, p. 430. At Galangung in Java, in 1822, there was a volcanic eruption. "In July, 1822, the waters of the river Kunir, one of those which flowed from its flanks, became for a time hot and turbid. On the 8th October following, a loud explosion was heard; the earth shook, and immense columns of hot water and

boiling mud, mixed with burning brimstone, ashes, and lapilli of the size of nuts, were projected from the mountain like a waterspout, with such prodigious violence that large quantities fell beyond the River Tandui, 40 miles distant (*sic*). . . . . It was remarked that the boiling mud and cinders were projected with such violence from the mountain, that while many remote villages were utterly destroyed and buried, others much nearer the volcano were scarcely injured. The first eruption lasted nearly five hours, and on the following days the rain fell in torrents, and the rivers densely charged with mud deluged the country far and wide. At the end of four days (Oct. 12), a second eruption occurred more violent than the first, in which hot water and mud were again vomited, and great blocks of basalt were thrown to the distance of seven miles from the volcano. There was at the same time a violent earthquake, ... and in the night of October 12th, 2000 people were killed."

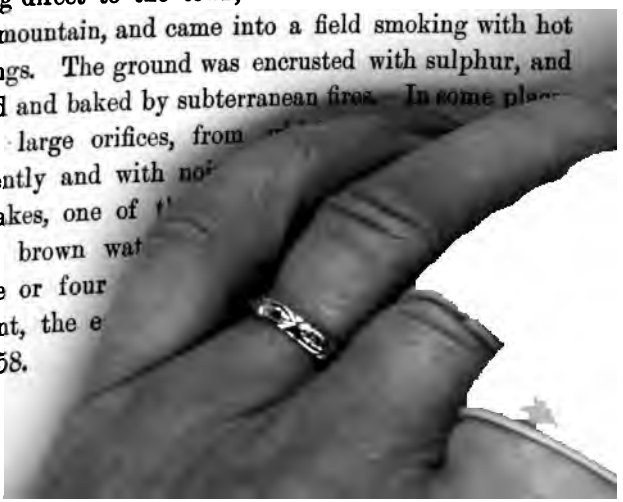
57*a*. The following is from Messrs. Stephens and Catherwood's account of a visit to El Infierno of the volcano of San Vicente, Central America:—

"Crossing a beautiful plain running to the base of the volcano, we left our animals at a hut, and walked some distance to a stream in a deep ravine, which we followed upward to its source, coming from the very base of the volcano. The water was warm, and had a taste of vitriol, and the banks were encrusted with white vitriol and flour of sulphur. At a distance of 100 or

200 yards it formed a basin, where the water was hotter than the highest grade of my Réaumur's thermometer. In several places we heard subterranean noises, and towards the end of the ravine, on the slope of one side, was an orifice about 30 feet in diameter, from which, with a terrific noise, boiling water was spouted into the air."—*Incidents of Travel in Central America*, 1854, p. 251.

There had been a series of earthquakes at San Salvador (about 45 miles distant from San Vicente in a direct line) which commenced on the 3rd of the preceding October, and for twenty days the earth was tremulous, sometimes suffering 15 or 20 shocks in twenty-four hours.—P. 252.

57*b*. "We looked down the perpendicular side [of the Mountain Aguachapa] to a plain 2000 feet below us, and in front, on another part of the same plain, were the lake and town of Aguachapa. Instead of going direct to the town, we turned round the foot of the mountain, and came into a field smoking with hot springs. The ground was encrusted with sulphur, and dried and baked by subterranean fires. In some pla[ces] were large orifices, from [which] violently and with no[ise] or lakes, one of [which] dark brown wat[er] three or four [feet] extent, the e[ffect] *P.* 258.



57*c*. They rode to the warm springs of Almolonga. The road crosses a spur of the volcano Quezaltenango and descends precipitously into a deep valley, in which, about a league distant, stand the village and hot springs. There is a good bathing house, outside of which is a beautiful natural reservoir, in which Indian men, women, and children, were bathing. (So that the water is not very hot.)—P. 359.

There are other accounts of volcanoes and earthquakes, but nothing which shows, either directly or indirectly, that steam or hot water either have or have not any connection with these convulsions of Nature.

58. In Quito, on July 19, 1698, during an earthquake, a great part of the crater and summit of the volcano of Carguirazo fell in, and a stream of mud and water issued from the broken sides of the hill.—*Principles*, p. 503.

59. The following is a remarkable case of the connection of a volcano with another mountain, and with an earthquake at great distances, and of the ejection of water. It is from the Encyclop. Brit., vol. xvii. p. 511. In 1797 it was proved that the volcano of Pasto was connected with the volcanoes of Quito. Black smoke had issued from Pasto for months, but suddenly disappeared at the moment when the city of Riobamba, 65 leagues distant, was destroyed by a terrific earthquake. The country round, namely 40 leagues from south to north, and 20 leagues from east to west, undulated with extreme violence for four minutes. Round

the mountain every town was thrown down, and two cities buried underneath impending mountains. The base of Mount Tunguragua, near Riobamba, was riven asunder, and poured out streams of water and mud which filled valleys 600 ft. deep. Suffocating exhalations were emitted from Lake Quilotoa, and, it is said, flames also. Violent shocks were felt for three months over a district 170 leagues from north to south, and 140 from east to west. The curious fishes, *Pimelodes cyclopum*, were found in the ejected water of the volcano.

Note.—Much more than what we have called the "average" effects of volcanoes and earthquakes appears to have been in operation in this case.

59*a*. In November 1835, Conception was shaken by a severe earthquake, and on the same day Osorno, at the distance of 400 miles, renewed its activity.—*Principles*, 1868, vol. ii. p. 93.

60. From the same volume we learn that, on March 26, 1812, subterraneous thunderings were heard, the ground undulated, and at one shock the fine city of Caraccas was destroyed, with 10,000 of its people. By this earthquake the great Lake of Maracaibo had its level lowered, and the riven earth at Valencia and Puerto Cabello poured forth enormous torrents of water.

61. "Mud, black smoke, and even flames were ejected at Messina in 1781."—*Cosmos*, vol. i. p. 209.

62. On May 7, 1860, several earth shocks were felt

at Myrdalen, a village in the southern district of volcano Kotlugia, after a rest of thirty-nine years. Next day the volcano threw up an immense quantity of water. There was a pretty heavy shower of ashes, accompanied by subterranean thunder.—*Athenæum*, July, 1860, p. 94.

63. Boussingault says, Chimborazo has ejected masses of mud, elastic fluids, and trachytic blocks.—*Cosmos*, vol. v. p. 335.

64. Next morning after the formation of Monte Nuovo, in 1538, an eye-witness says, the inhabitants of Puzzuoli were covered with a muddy and black shower which continued all day.—*Principles*, p. 367.

Another account says, jets of red hot lava, large rocks, and sometimes mud composed of a mixture of pumice, tuff, and water, were hurled into the air.—*Principles*, p. 370.

Ejections of Water, often Hot, from Earthquakes and from Risings and Sinkings of Strata, and from Earthquakes combined with Volcanoes.

65. "Hot water was ejected from an earthquake in Catania in 1818."—*Cosmos*, vol. i. p. 209.

66. There was a tremendous earthquake in Peru in 1746, 200 shocks in twenty-four hours. A volcano in Lucanas burst forth the same night, and so much water descended from the cone that the whole country was

overflowed; and in a mountain near Pataz three other volcanoes burst out, and frightful torrents of water swept down their sides.—*Principles*, p. 501.

67. In 1692, Port Royal, in Jamaica, with about 1000 acres adjoining, sank in one minute into the deep. In Clarendon precinct the earth gaped, and spouted up with prodigious force great quantities of water at twelve miles from the sea. In 1746 the ocean burst in upon the land, when the barrier of land sank into the sea; Lima was overwhelmed, and the present port of Callao formed. These convulsions were accompanied by eruptions of water and mud from several volcanoes among the Andes, many hundreds of miles distant.—*Phil. Trans. R.S.*, 1760, vol. xi. p. 469, and *Encyclop. Brit.*, Article "Volcanoes." *

68. The earthquake by which Jeddo was destroyed, in 1783, destroyed also twenty-seven other towns and villages, totally. Boiling rivers overflowed their banks, and at least 180,000 people are said to have perished.—*Quarterly Review*, Oct. 1863, p. 461.

Sir Rutherford Alcock, vol. i. p. 186, says of the same earthquake:—"Twenty-seven towns and villages were destroyed; the rivers, boiling and overflowing, inundated the whole country to complete the work of destruction."

69. Humboldt says, a very striking proof of the origin of hot springs by the sinking of cold meteoric water into the earth, and by its contact with a volcanic

* By the late Dr. S. P. Woodward.

focus, is afforded by the volcano Jorullo in Mexico. In Sep. 1759, Jorullo was suddenly elevated into a mountain 1183 feet high. Two small rivers, the Rio de Cuitimbo and Rio de San Pedro, disappeared, and some time afterwards burst forth again as hot springs, whose temperature he found in 1803 to be 186·4° Fahr.—*Cosmos*, vol. i. p. 219, and vol. v. p. 313.

70. In the afternoon of the day preceding the great Lisbon earthquake of 1755, the water of a fountain at Colares, twenty miles from Lisbon, was greatly decreased. On the morning of the earthquake it ran very muddy, and after the earthquake it returned to its usual state both in quantity and clearness. . . . This earthquake took its rise from under the sea (p. 458).—Rev. John Michell, *Phil. Trans. R.S.*, 1760, p. 463.

71. On Feb. 2, 1828, the whole island of Ischia was shaken by an earthquake. The hot spring of Rita, which was nearest the centre of the movement, was ascertained by M. Covelli to have increased its temperature.—*Principles*, p. 456.

Volcanoes, Earthquakes, Hot Water, and increasing Temperature of Hot Springs, sometimes all connected together.

72. M. Abich has proved the connection which exists between the thermal springs of Sarcin and the earthquakes which frequently visit the elevated districts in every second year. In October 1848, an undulatory

movement of the earth, which lasted for a whole hour, caused the temperature of the spring, which is between 111° and 115° Fahr., to rise immediately to a most painful scalding heat.—*Cosmos*, vol. v. p. 175.

73. Charpentier observed that the temperature of the sulphurous spring of Lavey (above S. Maurice, on the banks of the Rhone), rose from 87·8° to 97·3° F., during the Swiss earthquake of August 25, 1851.—*Cosmos*, vol. v. p. 175, note.

74. A tremendous earthquake, which destroyed a great part of St. Domingo, in 1770, caused innumerable fissures throughout the island, from which mephitic vapours emanated. Hot springs burst out where there had been no water before, but after a time they ceased to flow.—*Principles*, p. 494.

75. In the case of Stromboli, Etna, the volcanoes of the isle of Bourbon, and Kirauea, in Owhyhee, melted matter of unknown depth, covered for the most part with a thin pellicle of scoriform lava, and emitting copious volumes of steam or gas, was perceived in the craters.—*Dr. Daubeny*, p. 662.

76. The violent earthquake which devastated Syria in January 1837 was felt on a line 500 miles in length by 90 miles in breadth; more than 6000 persons perished; deep rents were caused in solid rocks, and new hot springs burst out at Tabereah.

77. "The town of Chittagong, in Bengal, was violently shaken by an earthquake on the 2nd of April, 1762, the earth opening in many places, and throwing

up water and mud of a sulphurous smell."—*Principles*, p. 494.

The following are very striking and significant. Has the water sunk so as to be now in process of conversion into steam?

Expected Eruption of Vesuvius.

78. "In the townships under Vesuvius," says a letter from Naples, "I find an uneasy feeling prevailing, and a general expectation of an earthquake. The less educated classes say that, as the cholera in 1856 was followed by an earthquake, so we may look out for another now. Among persons better educated, one said, 'I never go to bed without apprehension, and sleep with my door open.' The reasons for such apprehensions, when they are adduced, are these:—Vesuvius has long been dormant. Of late it has been making some ineffectual efforts to relieve itself, but nothing beyond a line of smoke by day and an occasional tongue of fire by night is perceptible. Then, all round Vesuvius, extending even to Castellamare, there is a perfect dearth of water, so much so that the arsenal of that place, which has always derived its water from mountain springs that have never failed even in summer, is now compelled to send to a considerable distance for water. Perhaps the most startling fact is the depression of the sea all round the bay. I have examined it at various places, and find that this depression is at least two

palms beneath the ordinary level. We have certainly had a month's calm weather, but still this is scarcely sufficient to account for the fact now stated."—*British Press* (Jersey), January 12, 1866. Is the water sinking down to the melted lava?

It has often been remarked that earthquakes (and sometimes also volcanic explosions) are preceded by a peculiar state of the atmosphere. The following is a case in point. About 3 P.M. on November 18, 1867, it having been a fiery hot day, when literally "the heavens were brass," in the Island of St. Thomas, the awful roar of an approaching earthquake was heard—a sound once heard never afterwards to be forgotten. In a moment the houses shook from door-step to roof; they cracked and groaned; the earth heaved and danced again, and much of the damage which the hurricane of October 29 had commenced was now completed. The population, some 15,000 to 20,000 souls, rushed into the streets, shrieking, praying, and imploring the divine mercy. All that night shock on shock succeeded one another in rapid succession. The shocks continued for several days. —*Illustrated London News*, Dec. 28, 1867.

Another account of the same event says, "The day was intensely hot, and almost without air—quite unseasonable, as generally after the end of October fine easterly breezes set in and cool the air. The roar of an earthquake was heard, the houses cracked, the earth heaved so violently that we could hardly stand, and the whole population rushed into the streets, some falling

on their knees, and all uttering the most pitiable cries. It was a fearful scene. The shock lasted two minutes and a half, a most unusually long time, minuted by some persons on board. Many of the inhabitants of St. Thomas and other West India Islands state that it was far the most severe they ever felt, yet owing to its vertical character, as distinguished from the horizontal and gyrative character of other earthquakes elsewhere, comparatively little damage was done beyond the severe cracking and straining of the walls. The tidal wave was, according to some accounts, 30, and according to others 60 feet high."

Are this heat and stillness of the air caused by the nearness of vast quantities of highly heated steam, which perhaps escapes from orifices on the island? No one seems to have been sufficiently calm, or sufficiently interested in the philosophy of the event, to have made the necessary observations.

SECTION XX.

PROPOSITION.—Humboldt says, most fearful shock of earthquake at Riobamba, unaccompanied by noise—Focus of shock of Quito earthquake must have been 246 miles distant—Focus of Callao earthquake 194 miles distant—M. Pissis found in South America earthquake shocks occur during rainy season and up to time of drought—Dana says, action of a volcano proceeds principally from fresh waters of island of Kilauea—He and Junghuhn say, Pacific volcanoes, however large, however rainy, support no rivers whilst crater is active *—No water on Etna while active—Submarine volcanoes.

* As if all the water was used up by the active volcanoes.

Temperatures and Pressures of Steam.

For formula and tables see text—Jukes's 'Manual' gives sp. gr. of fifteen varieties of igneous rock.—Humboldt's statement of portion of earth's surface shaken by great Lisbon earthquake—Examples of great propulsions of rocks by volcanoes—It is hoped now something has been done towards settling what is the motive power in volcanoes and earthquakes.

The following is a reprint, with additions, of certain parts of a tract published by the present writer in 1877, and entitled, 'What is, and what is not, the cause of activity in Earthquakes and Volcanoes?'

Proposition.

It is a Law of Nature that saturated steam of the temperature of 285·098° Fahr. gives a pressure of 52·529 lb. per square inch. At higher temperatures the pressure of saturated steam increases about in the enormously rapid ratio as the 4·5 power of the temperature. See text and tables and Appendix A following.

Humboldt mentions that the most fearful shock of earthquake at Riobamba was not accompanied by any noise whatever (possibly the focus was too distant for the noise to be heard). The tremendous noise which was heard at Quito earthquake, between 18 and 20 minutes [say 19] after the shock, taking the velocity of sound at 1142 feet per second, proved that the focus must have been distant 246 miles. And the noise of the earthquake of Callao in 1746 was not heard till 15 minutes after the shock, proving that the focus was

194 miles distant.* M. Pissis found that in South American districts most subject to earthquakes, in which he lived twelve years, the shocks occur "during the rainy season and up to the time of the drought," which is very significant of the water getting down to the melted matter.† However, every one knows that molten lava *very often* issues from the craters and sides of volcanoes, in immense quantities.

Mr. J. D. Dana, the geologist of the United States exploring expedition, says: "That the ordinary eruption and usual action of a volcano proceed principally from water gaining access to a branch or branchlets belonging to a particular vent, and not to a common channel below: the fresh waters of the island are the principal source of the vapour [evidently steam] of Kilauea."‡ And Dana and Dr. Junghuhn say that "the volcanoes of the Pacific isles, however large, however much exposed to heavy rains, support no rivers as long as they are in process of growth, or while the highest crater emits showers of scoriæ and floods of lava." § The like is true of Etna, for we read as follows: "An unusual silence prevails on the Val del Bove, Etna; for there are not torrents dashing from the rocks, nor any movement of running water in this valley such as may be almost universally heard in mountainous regions. Every drop of water that falls from the

* 'Cosmos,' vol. i. p. 203.
† 'Comptes Rendus,' Jan. 27, 1862.
‡ 'U. S. Exploring Expedition,' vol. x. p. 368.
§ Lyell's 'Manual,' 1855, p. 497.

heavens, or from the melting of ice or snow, is instantly absorbed by the porous lava." * It is beyond all question, then, that water descends to the melted lava and is converted into powerful steam, and produces explosions. I have about sixty more authorities, chiefly scientific men, who all contend more or less strongly, or it may fairly be inferred from the facts they state, that in their opinion earthquakes and volcanoes are caused by steam.

Let us now take an example of the *modus operandi* of submarine volcanoes. In the 'Nautical Magazine,' says Sir Charles Lyell, of April 1838, and in other works which he mentions, accounts are given of earthquakes, troubled waters, floating scoriæ, and columns of smoke, which have been observed between longitude 20° and 22° west, and about $\frac{1}{2}$° south of the equator.† This spot is 600 miles from the Isle of Ascension, the nearest land, and as the sounding is 2800 fathoms,‡ the hydrostatic pressure would be about 7492·8 lb., or 3·345 tons, on every square inch of the bottom.§ And the "troubled water," "floating scoriæ," and "columns of smoke," plainly signify that there must have been fire in the sea bottom at that

* 'Principles,' 1853, p. 405.

† 'Principles,' 1853, p. 405, and ibid. p. 436.

‡ See Lieut. Maury's Chart.

§ 'Steam, Earthquakes, and Volcanoes,' by R. A. Peacock, 1866, p. 33. 'Challenger Expedition,' vol. ii. p. 88. Intersection of 20° W. with equator is only 1780 fathoms deep. In fact, it is on the shallow bank which runs through the whole length of the Atlantic. This gives 2·126 tons per square inch.

immense depth. And fire + water = steam at all times and in all places, even *in vacuo;* and therefore steam was necessarily the cause of the submarine earthquake or volcano.

Capt. Toynbee, Marine Superintendent of the Meteorological Office, "tells of five earthquakes which were experienced in the same part of the Atlantic by ships: two in 0° 30′ N. and 30° W., three in 1° S. and 20° W."*

Temperatures and Pressures of Steam.—M. Regnault made a large series of most valuable experiments at the Paris Observatory, which are published in 'Mémoires de l'Institut,' tome xxi., 1847, now before me. Passing over all pressures (and their temperatures) less than 52 lb. per square inch, as being too small to be of any importance in earthquakes or volcanoes, I produce three tables founded on the rest. Table I. is thoroughly worked out by common logarithms, specially for this paper; to exhibit the difference per cent., which is exceedingly small, between experiment and calculation. Tables II. and III. have been calculated expressly for this paper, also by common logarithms. About 51·7† millimètres of mercury = 1 lb. avoirdupois. The differences per cent. are made conspicuous by being placed between thick lines, as they are very important. Regnault's numbers dealt with in Table I. are on his pp. 565, 569, 571, 573, 567.

Therefore the law of Nature is, that for all pressures,

* 'British Association Report,' 1875, Sections 167–9.

† More exactly 51·707.

TABLE I. *(further explained on next page).*

	Degrees Cent.	Regnault's Averages.	Calculations by Rule A.	Differences Millimètres.	Differences per cent.	Degrees Fahr.	Pressures in lbs. per square inch.
		Millimetres of mercury.					
1	140·61	2739.57	2716·13	23·44	−·836	285·098	52·529
2	143·075	2923·47	2911·6	11·87	−·408	289·535	56·309
3	144·16	3020·15	3001·03	19·12	−·637	291·488	58·0388
4	145·12	3099·49	3081·92	17·57	−·570	293·216	59·6033
5	145·62	3128·36	3124·72	3·64	−·116	294·116	60·431
6	146·286	3197·186	3182·45	14·736	−·463	295·315	61·5475
7	147·1175	3270·775	3255·67	15·105	−·461	296·8115	62·9635
8	147·505	3303·82	3290·24	13·58	−·412	297·509	63·632
9	147·88	3330·36	3323·96	6·40	−·193	298·184	64·2843
10	149·465	3479·31	3469·5	10·26	−·296	301·037	67·0988
11	150·295	3545·58	3547·65	2·07	+·058	302·531	68·61
12	150·41	3572·89	3558·59	14·3	−·402	302·738	68·822
13	151·55	3678·65	3668·43	10·22	−·279	304·79	70·946
14	151·856	3709·296	3698·36	10·936	−·296	305·341	71·525
15	153·31	3851·7	3843·16	8·54	−·222	307·958	74·3254
16	155·776	4106·203	4098·8	7.403	−·186	312·397	79·2695
17	156·06	4135·55	4129·07	6·48	−.157	312·908	79·8547
18	157·54	4298·965	4289·63	9·335	−·217	315·572	82·96
19	158·135	4360·42	4355·53	4·89	−·112	316·643	84·2345
20	158·35	4380·64	4379·54	1·10	−·025	317·03	84·6988
21	160·47	4641·28	4621·8	19·48	−·421	320·846	89·3841
22	160·815	4678·235	4662·2	16·035	−·344	321·467	90·1653
23	161·175	**4704·6775**	**4704·64**	·0375	−·001	**322·115**	**90·986845**
24	161·61	4751·3	4756·32	5·02	+·106	322·898	91·9856
25	161·7	4779·33	4767·065	12·265	−·26	323·06	92·1934
26	162·65	4894·896	4881·67	13·226	−·271	324·77	94·41
27	165·235	5208·985	5204·39	4·595	−·088	329·423	100·6511
28	167·58	5505·895	5511·27	5·375	+·097	333·644	106·586
29	172·385	6188·295	6183·98	4·315	−·07	342·293	119·596
30	172·81	6247·555	6246·42	1·135	−·018	343·058	120·8035
31	176·32	6765·235	6781·025	6·79	+·100	349·376	131·1428
32	177·396	6948·566	6951·855	3·289	+·047	351·313	134·4465
33	180·515	7462·332	7465·93	3·598	+·048	356·927	144·3885
34	181·17	7561·205	7577·54	16·335	+·216	358·106	146·547
35	184·12	8089·83	8096·46	6·63	+·082	363·416	156·583
36	186·7	8569·515	8572·465	2·95	+·034	368·06	165·79
37	187·04	8623·38	8636·9	13·52	+·157	368·672	167·0345
38	187·385	8676·425	8702·546	26·121	+·300	369·293	168·304
39	190·063	9206·696	9225·615	18·919	+·205	374·1134	178·4185
40	191·44	9488·355	9503·79	15·435	+·162	376·592	183·8
41	193·85	9995·45	10006·45	11·	+·109	380·93	193·521
42	194·14	10040·06	10068·53	28·47	+·282	381·452	194·717
43	194·195	10059·535	10080·07	20·535	+·204	381·551	194·945
44	195·533	10356·47	10369·6	13·13	+·127	383·96	200·545
45	195·57	10360·93	10377·66	16·73	+·161	384·026	200·7
46	197·475	10782·02	10801·2	19·18	+·178	387·455	208·8912
47	203·185	12140·6375	12151·77	11·1325	+·092	397·733	235·011
48	204·48	12432·93	12475·3	42·37	+·34	400·064	241·2725
49	209·64	13804·82	13832·88	28·06	+·203	409·352	267·523
50	211·94	14424·855	14473·67	48·815	+·397	413·492	279·916
51	216·516	15770·27	15817·1	46·83	+·296	421·729	305·898
52	219·4425	16623·1625	16725·765	102·6	+·613	426·996	323·47
	1	2	3	4	5	6	7

from about 52 lb. up to about 323 lb. per square inch, *the pressure of steam increases as the* $4\frac{1}{2}$ *power of the temperature.* This is clearly proved by Table I. preceding, because out of fifty-two series of experiments, not one of them differs as much as *a unit per cent.* from the formula, and forty-eight of them differ less than *half a unit per cent.* from the same formula, as appears by column 5. These close approximations to absolute identity between experiment and calculation cannot but be considered as very satisfactory definitions of Nature's law. To get a good basis to work from, I took the mean of eight nearly equal temperatures of Regnault's and the mean of four of his pressures corresponding which are printed in line 23 of the table in thickened figures; then by the formula, log. of 322·115° Fahr. $\times 4\frac{1}{2}$: log. of 90·986845 lb. :: log. of the given number of degrees Fahr. $\times 4\frac{1}{2}$ to its value in pounds. But by rule A (so called), i. e. by synthesis, the results can be obtained with half the labour. Rule A is: Multiply the log. of the given temperature Fahr. by $4\frac{1}{2}$, and from the product subtract the constant log. 9·327074486 (at this point the log. remainder = the number of lb. pressure per square inch), then add the constant log. 1·713355137, and the sum will be the log. of the given quantity in column 3, Table I.; columns 1 and 2 are by Regnault, and columns 3, 4, 5, 6, 7, by the present writer. The headings explain. *Note.*—All the pressures in the three tables include atmospheric pressure.

In Table II., Rule A requires a slight modification. That is to say, all quantities calculated by it have been reduced by 16 millimètres (= ·3094345 lb.) for every degree Centigrade after 219° C., and now the experi-

TABLE II.*

	Averages. — Degrees Cent.	Regnault's Experiments. — Millimètres.	Calculations by Rule A.	Deduct 16 mm. for each deg. C. after 219° C.	Calculations less deductions.	Differences per cent. + or −.	Degrees Fahr.	Col. 5 reduced to lb. pressure per sq. inch.
1	220·15	16855·65	16951·435	18·4	16933·035	·459+	428·27	327·377
2	220·21	16886·	16974·57	19·36	16955·21	·528+	428·378	327·908
3	221·82	17346·3	17943·45	45·12	17448·33	·588+	431·276	337·445
4	221·91	17374·59	17523·	46·56	17476·44	·586+	431·438	337·99
5	222·04	17398·58	17565·85	48·64	17517·21	·682+	431·672	338·773
6	223·12	17790·11	17924·65	65·92	17858·73	·386+	433·616	345·382
7	223·15	17803·22	17934·7	66·4	17868·3	·366+	433·67	345·567
8	223·20	17816·98	17951·45	67·2	17884·25	·378+	433·76	345·875
9	224·27	18123·25	18312 9	84·32	18228·58	·583+	435·686	352·534
10	224·31	18232·65	18326·56	84·96	18241·60	·049+	435·758	352·786
11	224·38	18250·3	18350·4	86·08	18264·22	·077+	435·884	353·226
12	228·84	19742·54	19921·1	157·44	19763·66	·107+	443·912	382·223
13	228·89	19777·18	19939·27	158·24	19781·03	·019+	444·002	382·558
14	228·97	19806·63	10968·4	159·52	19808·88	·011+	444·146	383·097
15	232·56	21127·	21309·43	216·96	21092·47	·1635—	450·608	407·921
16	232·58	21136·72	21317·1	217·28	21099·82	·175—	450·644	408·016
17	232·64	21139·3	21430·4	218·24	21212·16	·083—	450·752	408·54
18	232·64	21144·02	21330·4	218·24	21112·16	·579—	450·752	408·54
	1	2	3	4	5	6	7	8

For experiments, columns 1 and 2, see pages 571–3 of 'Mémoires de l'Institut,' tome xxi., 1847. The experiments are here numerically arranged in column 2.

ments in column 2 will be seen to agree within a trifle with columns 4, 5; that is to say, they agree within *a fraction of a unit per cent.* + or −, as appears

* This series of experiments treated in Table II. is not of much practical importance. For we shall see presently in Appendix A, that at the very highest temperatures the modifications in column 4 practically vanish.

when we compare them with column 6. There were eighteen pairs of readings with two mercurial centigrade thermometers, of which the averages are given in column 1. *Note.*—A *vacuum* is no impediment to the production and power of steam.

Beyond the limits of the preceding tables I cannot give rigorous proofs of excessive pressures of steam, Regnault having carried his experiments no higher than 232·64° C. (= 450·752° Fahr.) giving a pressure of 408·49 lb. per square inch.* However, steam certainly propelled lapilli 40 miles at Galangung, giving a force of not less than 17,534 tons per inch, as stated already; and the reader will see presently some other proof of far greater pressures of steam. The custom of scientific men is to write down the highest temperature of subterranean fusion at 3000° Fahr. Sir W. Armstrong did so in his address at Newcastle in 1863, p. lviii,† which, 3000° minus the 450·752° Fahr., *leaves* 2549·248° *Fahr. to be accounted for, which will most certainly give an enormous pressure,* and *we are bound to consider it.* Accordingly I propose that steam pressures should be taken to increase as the $4\frac{1}{2}$ power of the temperatures, or a very little less, as already explained in Table II.; only provisionally, however,

* MM. Arago and Dulong carried their experiments up to a pressure of 50 atmospheres = 735·33 lb. per square inch, which they found was given by steam of 510·6° Fahr. This temperature by the present writer's calculation only gives a pressure of 708·743 lb. Nevertheless both results prove a rapid increase of pressure up to 510·6° Fahr.

† To the British Association. According to Prof. Daniell, melted iron is about 2700°, sometimes 2800°, Fahr.

until time produces evidence to confirm or refute the theory. Just as Dalton's atomic theory and the undulatory theory of light have never been absolutely proved, yet they are extensively believed in. It can do no harm to work the question by Rule A. What is the possible force of saturated steam of 3000° Fahr. (= 1648·88° C.) per square inch?

	tons.	
Log. of 3000° Fahr. $4\frac{1}{2}$ − 9·32704486 − log. of 2240 lb. = tons per square inch	932·65	
Deduct 16mm. for each degree C. after 219° = viz. 1648·88° − 219° = 1429·88 C. × ·3094345 lb. (= 16 mm.) = less than 4 cwt., viz.	·1975	$\frac{1}{4732}$
Total theoretical pressure of steam of 3000° Fahr. per square inch	932·4525	

TABLE III. (Theoretical.)

Degrees Cent.	Degrees Fahr.	$4\frac{1}{2}$ power of Temperatures By Rule A.	Deductions.	Net.		
		lb.	lb.	lb.	tons.	lb.
219·	426·2	320·764	0·	320·764		320
260·	500·	658·198	12·687	645·511		645
265·88	510·6*	723·251	14·508	708·743		
315·55	600·	1494·9	29·87	1465·03		1465
371·11	700·	2991·33	47·062	2944·268	1	704
426·66	800·	5455·45	64·257	5391·193	2	911
482·22	900·	9268·66	81·44	9187·22	4	227
537·77	1000·	14891·	98·638	14792·362	6	1352
593·33	1100·	22866·13	115·83	22755·03	10	355
616·11	1141·†	26959·4	122·879	26836·521	11	2196
		tons.	tons.	tons.		
1648·88	3000·	932·65	·1975	932·4525	932	1013
8061·	14541·	1132810	1·08		1132809	
1	2	3	4	5	6	

* MM. Arago and Dulong's highest. † Daniell's greatest heat of common fires.

Either column 3 or column 5 of the Table may be adopted; their differences are insignificant.

Jukes' 'Manual,' 1862, pp. 61–89, gives the specific gravity of 15 varieties of igneous rock, the mean of all being 2·696, taking water as *unity* at 62½ lb. per cubic foot. Therefore, mean weight of a column of the igneous rocks, one inch square and one foot high, is 1·17013 lb.; and it would require a column of 31,219 feet or 5·9 miles high to weigh the 12 tons of Table III. But a force of 12 tons would not propel the small column to the height of 5·9 miles, because there would be atmospheric resistance to overcome. Jukes says that "Bischoff arrives at the conclusion that columns of lava 29,348 feet to 35,209 feet in altitude might be lifted by steam from depths of 88,044 feet and 105,627 feet respectively, provided the communications between the sea and the volcanic focus were not interrupted."* 35,209 ft. + 105,627 ft. × 1·17013 lb. = 164,796 lb. = 73 tons only, exclusive of the force required to overcome atmospheric resistance. Therefore the Callao earthquake, presently to be described, which had a force of more than 500 tons per square inch, proves that Bischoff was much within the mark. Jukes says also that "water will readily pass through porous substances which are quite impermeable to it when converted into steam, so that it is possible to conceive pent-up reservoirs of steam receiving continued accessions from water arriving by channels which the steam cannot escape by."† This is quite intelligible, because, when the steam ascends through the porous strata, it

* Jukes' 'Manual,' 1862, p. 343. † Ibid.

will come among strata cool enough to condense it into water, when it will descend and again be converted into steam; and then ascend again, and so on. This accounts for springs becoming hot and muddy, and diminishing in quantity of water immediately before earthquakes, phenomena which occurred in the Lisbon and other earthquakes, some of the spring water descending no doubt with the condensed steam.

We have proofs that the focus is sometimes at a great distance. For instance, in the earthquake of Lima and Callao, 28th October, 1746, a noise like an underground thunderclap was heard "a quarter of an hour after the shock." * And, taking the velocity of sound at 1142 feet per second, we have for the distance of the focus 194 miles. And the Quito earthquake with a *focus* at the distance of 246 miles.

Humboldt says: "It has been computed that on the 1st of November, 1755, a portion of the earth's surface, four times greater than that of Europe, was simultaneously shaken." † The area of Europe is 3,650,000 square miles ‡ × 4 = 14,600,000 square miles, and the total area of the earth, seas, and oceans being 196,677,000 square miles, it follows that nearly $\frac{1}{13}$th of the whole surface received a shock by the earthquake of Lisbon. In August 1868, earthquake shocks extended all across the Pacific; in fact more than half round the earth.§ For want of sufficient data I am unable to institute any comparison between the bulk

* 'Cosmos,' vol. i. p. 203.
† Ibid., p. 209.
‡ Butler's 'Atlas,' 1868.
§ Scrope, pp. 494–7.

of either of the parts shaken in 1868 and 1755 with the other.

Volcanoes.—The following shocks, though caused by forces vastly less than those operating from deep-seated *foci*, are yet much greater than the forces of human artillery, great as those have become. What was the power acting in No. 1, I have no information; but steam was palpably and clearly the active power in No. 2.

1. M. Bouguer tells us, that he met with stones in South America, of 8 or 9 feet diameter, that had been thrown from the volcano Cotopaxi, "to the distance of more than 3 leagues." One of these, supposing it to be of granite, would weigh 200 tons.* And having regard to the *vertical* direction of craters, the projectile probably rose to an immense height before it descended at 3 leagues distance.

2. The late Mr. Scrope was very learned in all that relates to volcanoes, and carried off a gold medal for his writings thereon. He gives a picture of an explosion of Vesuvius in October 1822.† We see an immense column of stones, &c., shooting up to a height of apparently 4 miles, and then an immense white fleecy cloud of vapour expands horizontally for miles, which is evidently steam. Indeed, he says it is so to the extent of 999 parts in 1000.

No doubt the crushing of rocks produces a great quantity of heat, but simple heat has no explosive power whatever. Look at the many blast furnaces,

* Phil. Trans. R. S. 1760, p. 457. † Scrope on 'Volcanoes,' loc. cit.

the hottest things on earth; they *never* explode, unless water gets in, and then a *steam* explosion occurs. And the sun himself, the largest and hottest body known—he never explodes. What peaceable things are the hottest fires! Steam, on the contrary, burst a boiler lately and destroyed forty-five valuable lives. Therefore *steam is*, and heat produced by the crushing of rocks *is not*, the cause of activity in earthquakes and volcanoes.

All experiments, even the very best (among which I think, M. Regnault's may be reckoned), are liable to small inaccuracies. But the calculations by Rule A are not thus liable (each has been worked at least twice), because they average the whole mass of experiments, each one with all the rest, by an arithmetical law. Perhaps the calculations have cleared Tables I. and II. of minute errors.

The *cause* of earthquakes and volcanoes has been a *desideratum* ever since science began to be cultivated. It is hoped that something has now been done towards settling the question.

POSTSCRIPT.

Any attempt which has been, or may be made, to define the motive power which causes volcanoes and earthquakes without taking electricity into consideration, would be like the play of Hamlet with the part of Hamlet left out.

APPENDICES.

APPENDIX A.

"Rule A," so called in Tables I., II., and III., at the head of every column worked by it, is this very simple law of nature, namely:—

The pressure of saturated steam at 285·098° *Fahr.* (*which gives a pressure of* 52·529 *lb. per square inch*) *increases as the* 4·5 *power of the temperature Fahr.* In this way the following example is worked:—

Hydrogen burning in oxygen { 8061° C. or 14,541° F.

By Rule A, *ante* p. 111,
14541° F.
= log. 4·1625943

$4\frac{1}{2}$

16·6503772
2·08129715

18·73167435
9·327074486*

9·404599864
\+ 1·713355137 the constant on p. 111, *ante*.

11·117955001 = 131206340000 millimètres of mercury.

51·707 ——— = 2537496600 lb.

2240 ——— = 1,132,810 tons per sq. in.

1,132,810 tons × 1296 (the number of sq. in. in a supl. yard) = 1468 millions of tons, which is perhaps equal to the force operating in the great Lisbon earthquake; the *focus* being assumed to be a superficial yard in area, and neglecting the fraction of a million of tons.

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* This is the equivalent of adding the *second* term of the proportion and deducting the *first*. See *ante*, p. 111.

Rule for Table II., p. 112, *ante*.

14,541° F. = 8061° C.

$$- \quad 219$$

$$7842 \times \cdot 3094345 \text{ lb.} = \frac{2426 \cdot 585, \text{ \&c.}}{2240} = 1 \cdot 08 \text{ ton,}$$

the modification, which is such a trifle that it may be neglected.

This force has, we submit, been attained by fair and legitimate calculation, founded on well-established facts; and cannot be reasonably or fairly objected to. If so, it follows that saturated steam produced by the great heat of hydrogen burning in oxygen is the motive power in volcanoes and earthquakes: which was to be demonstrated.

And the melted lava issuing from volcanoes, is rock newly melted by hydrogen burning in oxygen.

APPENDIX B.

Extract from Vol. 2 of Sir Charles Lyell's 'Principles of Geology,' 10th, 11th, and 12th editions, pp. 56–8.

"*Galangoon, Java*, 1822.—The mountain of Galangoon (or Galung Gung) was in 1822 covered by a dense forest, and situated in a fruitful and thickly peopled part of Java. There was a circular hollow at its summit, but no tradition existed of any former eruption. In July 1822 the waters of the river Kunir, one of those which flowed from its flanks, became for a time hot and turbid. On October 8 following a loud explosion was heard, the earth shook, and immense columns of hot water and boiling mud, mixed with burning brimstone, ashes, and lapilli of the size of nuts, were projected from the mountain like a waterspout, with such prodigious violence that large quantities fell beyond the river Tandui, which is 40 miles * distant. Every valley within the range of this eruption became filled with a burning torrent, and the rivers, swollen with hot water and mud, overflowed their banks and carried away great numbers of people who were endeavouring to escape, and the bodies of cattle, wild beasts, and birds. A space of 24 miles between the mountain and the River Tandui was covered to such a depth with bluish mud that people were buried in their houses, and not a trace of the numerous villages and plantations throughout that extent was visible. Within this space the bodies of those who perished were buried in mud and concealed, but near the limits of the volcanic action they were exposed, and strewed over the ground in great numbers, partly boiled and partly burnt.

"It was remarked that the boiling mud and cinders were

* On examining a large scale chart of Java at the British Museum these are found to be 40 geographical miles of 6075·6 English feet each, and are so calculated, Sec. X., equal to 46 English miles.—R. A. P.

projected with such violence from the mountain, that while many remote villages were utterly destroyed and buried, others much nearer the volcano were scarcely injured.

"The first eruption lasted nearly five hours, and on the following days the rain fell in torrents, and the rivers, densely charged with mud, deluged the country far and wide. At the end of four days (October 12th) a second eruption occurred more violent than the first, in which hot water and mud were again vomited, and great blocks of basalt were thrown to the distance of seven miles from the volcano; there was at the same time a violent earthquake. And in one account it is stated that the face of the mountain was utterly changed, its summit broken down, and one side, which had been covered with trees, became an enormous gulf in the form of a semicircle. This cavity was about midway between the summit and the plain, and surrounded by steep rocks, said to be newly heaped up during the eruption. New hills and valleys are said to have been formed, and the rivers Banjarang and Wulan changed their course, and in one night (October 12th) 2000 persons were killed.

"The first intimation which the inhabitants of Bandong received of this calamity on October 8th was the news that the river Wulna was bearing down into the sea the dead bodies of men, and the carcasses of stags, rhinoceroses, tigers, and other animals. The Dutch painter Payen determined to travel from thence to the volcano, and he found that the quantity of the ashes diminished as he approached the base of the mountain. He alludes to the altered form of the mountain after the 12th, but does not describe the new semicircular gulf on its side.

"The official accounts state that 114 villages were destroyed, and above 4000 persons killed." *

* Van der Boon Mesch, *De Incendiis Montium Javæ, &c.* (Lug. Bat. 1826); and Official Report of the President, Baron van der Capellen; *also* Von Buch, *Iles Canar.*, p. 424.

APPENDIX C.

Van der Boon Mesch, De incendiis montium Javæ, &c. Lugd. Bat., 1826.

The following three extracts refer to the volcanic explosions of Mount Galangung in October 1822. The second extract gives positive and distinct proof of the existence of underground thunder and lightning. Observe, the clouds are so dense and dark that they hide the sky and the mountain; terrible lightnings (terribilia fulgura) burst out, and, as lightnings are wont to do, some they strike and kill, others are wounded. We must all admit in future that true thunder and lightning on a grand scale is sometimes one of the terrible developments of volcanoes in explosion. Léopold de Buch's "mugissements horribles," quoted in Appendix D, will be nothing else than the same identical underground thunder. Van der Boon Mesch says, p. 44:—"Jam vomere cœpit mons aquas fervidas et moles limi ac sulphuris flagrantis harumque fluctus obruunt agros plus decem millibus a monte distentos.

Pp. 44–5. "Interdum nubes quæ cœlum et montem abscondunt, elidunt terribilia fulgura; his icti alii concidunt alii vulnerantur . . . . undique cadunt imbres limi, cineris et lapidum horumque magnitudine nucis."

P. 46. "Magnæ basaltæ rupes ad sex et septem millia passuum ab ipso monte erant projectæ." This allegation has been very unjustly condemned as an exaggeration.

APPENDIX D.

Description Physique des Iles Canaries, suite d'une indication des principaux Volcans du Globe, par Léopold de Buch; traduite de l'allemand par C. Boulanger, ingénieur des mines. Revue et augmentée par l'auteur. Paris, 1836.

P. 424.—"Galungung, un peu au sud de Talaga Bodas et au milieu de la vallée entre les deux chaines de volcans. L'éruption de ce volcan en 1822 est fort interessante, tant pour la connaissance des phénomènes volcaniques tels qu'ils s'exercent sur l'île que pour la théorie des volcans en général, et mérite par conséquent une attention particulière. Déjà pendant le courant du mois de juin 1822, les eaux de la rivière *Chikunir*, qui descend de la montagne alors très cultivée et peuplée, s'étaient troublées; elles déposaient une poudre blanche, exhalaient une odeur sulfureuse, devenaient acides et commençaient à s'échauffer considérablement, trahissant ainsi le grand mouvement de dissolution qui se développait dans l'intérieur. Le 8 d'octobre, à une heure après-midi, des mugissements horribles se firent entendre; la montagne se couvrit immédiatement d'une fumée épaisse, et des eaux chaudes, sulfureuses et limoneuses se precipitèrent de tous côtés sur ses flancs, en dévastant et emportant tout ce qu'elles rencontraient sur leur passage. On vit avec étonnement, à *Badang*, la rivière de *Chiwulan* charrier vers la mer un nombre immense de cadavres d'hommes, de bestiaux, de rhinoceros, des tigres, de cerfs, et même jusqu'à des maisons entières. Cette éruption d'eau chaude limoneuse continua pendant deux heures, qui suffirent pour consommer la ruine et la dévastation de toute une province. A trois heures elle avait cessé, mais il tomba alors une pluie épaisse de cendres et de lapilles qui achevèrent de brûler

les arbres et les champs épargnés jusqu'alors. A cinq heures, la tranquillité était parfaitement rétablie, et la montagne se découvrit. Mais ce peu de temps avait suffi pour couvrir de limon tous les villages, toutes les habitations jusqu'à plusieurs lieues de distance. Le 12 d'octobre, à sept heures du soir, ces horribles phénomènes se renouvelèrent. Un tremblement de terre général fut suivi par une éruption, dont on entendit le bruit pendant toute la nuit. De nouveaux torrents d'une eau boueuse et chargée de limon, se précipitant vers la vallée, entraînèrent avec eux des rochers et des forêts entières, de manière que des collines furent élevées dans les parties où peu de moments auparavant il n'y avait qu'une plaine. Il fut bientôt impossible de reconnaître cette vallée auparavant si fertile et si peuplée. Tous les habitants, sans pouvoir seulement songer à la fuite, furent enterrés sous ces limons, et l'on pense que pendant cette nuit plus de deux mille personnes ont perdu la vie dans le seul district de *Singaparna* au nord de cette terrible montagne. Le volcan avait considérablement changé de forme pendant ce laps de temps; il avait diminué de hauteur et était tronqué; depuis cette éruption, il resta en mouvement; il fumait encore le 12 novembre et lançait en l'air des nuées de vapeurs. M. Payen, naturaliste et peintre, qui s'approcha de la montagne peu de jours après l'éruption, et qui l'a décrite dans une lettre à M. Reinwardts, ne put avancer vers le volcan. Le limon et des crevasses nombreuses l'en empêchèrent, et les mêmes difficultés se représentèrent pendant tout le mois de novembre (Boon Mesch, p. 47). M. Blume, botaniste, a examiné, sur les lieux, ce limon dévastateur; il était d'une couleur brune jaunâtre, terreux, friable, exhalait une odeur sulfureuse et brûlait sans difficulté. Il n'y a point de doute qu'il ne fût en grande partie composé de soufre. Les Malais nomment ce limon *Buah*,

c'est-à-dire pâte, et il est evident que cette matière est analogue à la *Maja* de Quito, qui, en 1798, couvrit la malheureuse ville de Riobamba.

"Il semble donc que l'effet de l'action volcanique dans l'île de Java serait de développer en même temps une immense quantité de vapeurs sulfureuses et aqueuses, qui s'emparant de la roche dont l'intérieur de la montagne est composée, la décomposent jusqu'à en faire une pâte, un *Buah*, et enfin, quand la masse solide est détruite de manière à ne pouvoir plus opposer assez de résistance, les vapeurs se font jour au-dehors, et la matière fluide s'échappe par les crevasses, non comme un courant de lave visqueuse, mais comme des torrents d'eau qui jaillissent par chaque petite ouverture qu'elles peuvent atteindre.

"On ne peut donc regarder toutes ces eaux que comme des eaux distillées, et il faut croire qu'il en est de même de celles de ces deux rivières qui sortent du cratère du volcan d'Idjen; car ce cratère se trouve presqu'à la cime d'une montagne isolée, qui n'est dominée par aucune autre montagne avoisinante."

APPENDIX E.

The following is an extract from the 'Daily Telegraph' of August 18, 1882. *If it can be depended on, the well-known statement as to the 'Valley of Poison,' which we have quoted on p.* 49, *ante, falls to the ground:—*

"Another romantic tradition has been refuted, another thrilling illusion dispelled, by Dr. Otto Kuntze's discovery that the lethal capacities of Pakamaran, the renowned Javanese Death-Valley, are as utterly fabulous as the Norwegian Kraaken or Richard of Gloucester's hump. It is no longer permitted to us to believe that the effects of the subtle poison given off by the 'Deadly Upas Tree' have bestrewn that dismal vale with countless carcases of savage beasts, serpents, and birds, or that a certain death awaits any foolhardy traveller attempting to cross it; for the eminent German explorer has paid Pakamaran an exhaustive visit, and reports it to be as healthy as any other part of the island. In the way of corpses, he did not see so much as a dead fly within its precincts. He describes it as a small depression in a gorge of the Dieng Mountains, about seven square mètres in size, and forlorn of vegetation. It is approached by two footpaths, winding downwards from the hills by which it is surrounded. By one of these paths Dr. Kuntze entered the Death Valley, despite the entreaties of his guides and servants, one of whom repeatedly strove to hold him back by force, and, having traversed Pakamaran in every direction, quitted it by the other path. The natives had assured him that he would find the valley choked up by

skeletons, as even the swiftest birds flying above it would drop down stone-dead, slain by its poisonous exhalations. In vain, however, did he look about for a single bone; nor could he detect the least unpleasant odour. Dr. Kuntze pronounces Pakamaran to be an imposture, the offspring of ignorance and superstition. Unable to dispute his sentence, we are bound, not altogether without regret, to relegate the death-dealing vale to the limbo of exploded myths."

APPENDIX F.

Why not work with steam of 300 *lb. pressure on the square inch?*

The present investigation by means of M. Regnault's admirable series of experiments on the relation which *temperature* bears to *pressure* in saturated steam may be applied to another purpose of great practical advantage to mankind. It happened to the present writer some eight or ten years ago to be aboard one of Her Majesty's steamships, then commanded by a personal friend of his, in the harbour of Gorey, in the Isle of Jersey. He was then informed (to his great astonishment) that the power employed to work the paddles was no greater than 7 lb. to the square inch! Now the two last columns of Table I., at p. 110, *ante*, prove beyond all dispute that a temperature of about 285° Fahr. gives a pressure of about 52½ lb. per square inch, and that a temperature of about 427° Fahr. gives a pressure of about

323½ lb. per square inch. Why not work the paddles and screws of steamships (to say nothing of other machinery) with a steam power of 300 lb. per square inch? Its temperature would be well within the power of a common fire, which is 1141° Fahr. (see p. 67, *ante*). The boilers used should be spheres (the strongest form), and from 6 feet to 9 feet in diameter, made of cast steel ½-inch thick, which has a cohesive power of about 30 tons per square inch,* which gives a large margin of extra strength to prevent boiler explosions.

A boiler 5 feet diameter and 21 feet long would contain 412·335 cubic feet.

A boiler sphere 9 feet diameter would contain nearly as much, say 381·7044 cubic feet.

The convex surface of a sphere 9 feet diameter is 254·4696 superficial feet, of which 230 feet would be exposed to the fire by leaving an open space between the boiler and the brickwork. And the remaining 24½ feet (contained within a circle of about 5 feet 7 inches diameter at the summit of the boiler) would also have brickwork resting on it to keep in the heat, and the safety-valve would be padded on the top with cotton-waste or tow steeped in oil, to prevent the steam from receiving a chill in cold weather. The steam pipes and cylinders would also be padded on their outsides for the same reason. The boiler would rest on an iron ring carried on three cast-iron pillars standing in the fire, and strongly fastened.

There ought to be two engines in each large steamer which would work either together or separately, and a

* In 'Weale's Engineers' Pocket Book for 1857,' p. 161, the cohesive power of cast steel is stated at 134,256 lb. per square inch, or 29·967 tons per square inch for the boiler.

suitable number of these boilers, which would supply 300 lb. steam to one or both these engines. By these means the ocean could be crossed in a very short time. The cylinders ought to be of cast steel an inch thick.

As a civil engineer the present writer has built sixty viaducts and bridges on the Trent Valley and North Staffordshire Railways, and has done a good deal of other engineering work, though he never joined the Institute of Civil Engineers. Messrs. Stephenson, Bidder, and Gooch were the chief engineers of the two railways named.

There is a very interesting leading article in the *Daily Telegraph* of September 6, 1882, in which an account is given of two champion ships now being built on the Hudson river; one, the *Meteor*, is now on the stocks at Nyack, and is called a "dome steamer;" the other is being built at Hastings, and is called the *Oceanic*. "She resembles a velocipede. The hull does not touch the water, but rests upon three steel spheres, all of which are fitted with paddles." There is no mention in either case whether the steam is of more than the ordinary power.

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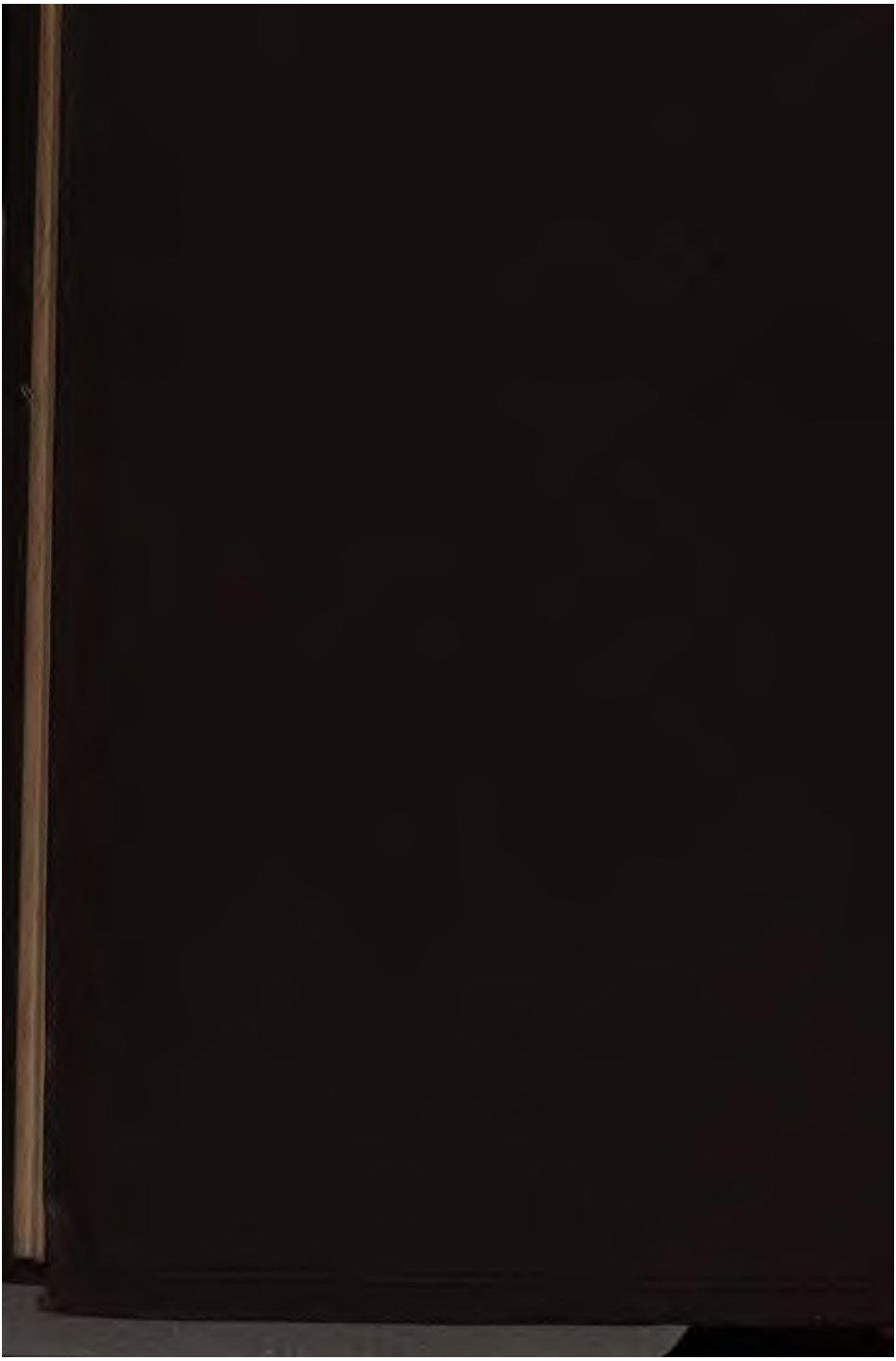
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